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COMPREHENSIVE SUBGRADE DEFLECTION ACCEPTANCE CRITERIA

PILOT IMPLEMENTATION

FINAL REPORT

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16. Abstract

This report has presents the findings of implementations of pilot specifications for subgrade acceptance based on measured deflections. The reconfigured rolling wheel deflectomter (RWD), portable truck-mounted deflection measurement systems, and dynamic cone penetrometer (DCP) were utilized on four subgrade construction projects during the 2001 construction season. Comparative nuclear density readings were obtained at selected locations within each project. Comparative soil stiffness gauge readings were also obtained on 2 of the pilot projects

The research findings from this and previous study phases indicate that deflection test results may be appropriate for identifying areas of poor in-place stability within constructed subgrades. However, deflection testing alone may not provide all of the data necessary to properly differentiate acceptable and non-acceptable subgrade stabilities. It is important to note that deflection test results are related to the moisture-density conditions at the time of testing. Soils that show acceptable results (i.e., low deflections) may subsequently weaken due to changes in moisture content, freezing/thawing, etc. In instances where subgrade acceptance is well in advance of base course application, subgrade moisture changes may result in decreased soil support. For those conditions where soil compaction has been conducted at a moisture state near optimum, surface deflections should be correlated to the achieved level of compaction.

The overall objectives of this research have been met, particularly in the development of useful correlations between subgrade deflections and in-place subgrade stability as measured by the California Bearing Ratio (CBR). Deflection data collected to date using instrumentation on the axles of loaded quad-axle trucks indicates this data source should be adequate for acceptance testing. It is recommended that implementations of deflection acceptance testing be conducted during the 2002 construction season on selected projects using a deflection threshold of 1.50 inches to identify areas which would not provide sufficient stability for subsequent construction operations. For use within Year 2002 implementations, this threshold value is recommended for use to identify potentially "failed" test locations. The project engineer should retain the right to require corrective actions to improve subgrade conditions based on the magnitude and extent of failed readings.

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COMPREHENSIVE SUBGRADE DEFLECTION ACCEPTANCE CRITERIA

PILOT IMPLEMENTATION FINAL REPORT
WI/SPR 04-02
WisDOT Highway Research Study # 98-1
SPR # 0092-45-95

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1.0 INTRODUCTION

This report documents the results of pilot implementations of deflection acceptance specifications conducted during the 2001 construction season. These pilot implementations were conducted to supplement the database developed during earlier phases of this research effort as well to determine the feasibility of specification implementation as related to the normal sequence of subgrade construction. The previous results of Phase I and II activities have been documented in WisDOT Report WI/SPR-03-00 dated March, 2000. Phase III research results have been documented in WisDOT Report WI/SPR-02-01 dated January, 2001.

Pilot implementations were conducted on four subgrade construction projects located in Wisconsin as follows:

1. Project ID 1065-04-72 - CTH SS Interchange, Waukesha County
2. Project ID 4015-00-70 - STH 57, Ozaukee County
3. Project ID 1152-07-75 - USH 41, Oconto County
4. Project ID 4015-08-71 - STH 57, Sheboygan County

Subgrade deflections were collected with an instrumented quad-axle dump truck on all pilot implementation projects. Comparative rolling wheel deflectometer (RWD) data was also collected on all but the CTH SS interchange project. Subgrade penetration tests using the automated and/or hand-held dynamic cone penetrometer (DCP) were also collected on all projects. During field deflection testing, representatives from WisDOT were present on all projects to conduct in-place moisture-density tests using the nuclear gage. WisDOT personnel also utilized the Soil Stiffness Gauge for data collection on the CTH SS and STH 57, Ozaukee County projects.

Based on the results of quad axle truck testing completed during previous study phases, a simplified sensor configuration was developed to exclude all instrumentation previously located outside the physical limits of the truck body. This revised configuration included four sensors located below the front bumper and two sensors located on the front axle. Front bumper sensors were located at positions coincident with the center of each front wheel and at positions 2 ft inside of each wheel center. Axle mount sensors were positioned

2 ft inside each wheel center, along the same line of the interior bumper mounted sensors. An automated marking system was also fabricated and installed along the front bumper rack. The sensor and paint marking locations based on the revised configuration are schematically illustrated in **Figure 1.1.1**.

Based on the results of contract bids for the included pilot implementation projects, all subgrade tests were conducted using a dedicated quad axle dump truck supplied by Michels Materials, Inc., located in Brownsville, WI. Prior to the start-up of testing, a modified bumper-mounted sensor rack and marking system were developed which could easily be field-installed in approximately 10 minutes or less. Axle-mounted sensor brackets which were developed during previous study phases were re-utilized. The dedicated quad-axle truck was also equipped with an on-board distance measuring device which included positioning targets mounted on the drive shaft. An additional proximity sensor was mounted to existing bracketing located adjacent to the drive shaft which provided voltage pulses at approximately 5.5 inch intervals.

2.0 FIELD TEST PROGRAM

Subgrade deflection tests were conducted at selected subgrade construction sites in Wisconsin during the Year 2001 construction season. The collected deflection and/or penetration data was not used for subgrade acceptance on any of the included projects. However, WisDOT personnel were on site to observe subgrade deflections produced by the loaded quad-axle dump truck and/or the RWD and these observations were used to identify "failed" subgrade locations that would be considered unacceptable.

The field test results for each pilot project are presented in both tabular and graphical form. Tabular results provide indications of in-place moisture-density, soil stiffness (where measured), CBR, and rolling deflections for selected locations where CBR and/or nuclear tests were performed. Graphical results provide profiles of quad axle and RWD deflections as well as comparative rolling deflections for locations where both type of equipment were used.

2.1 CTH SS - Waukesha County

Subgrade deflection tests were conducted on three occasions between May 31 and July 11, 2001 on portions of frontage roads and ramps being constructed as part of the CTH SS interchange reconstruction under Project ID 1065-04-72. All subgrade testing was conducted using only the instrumented quad-axle dump truck supplied by Michels. Comparative DCP testing was also conducted at selected locations by Marquette staff. Additional soil testing, including Nuclear Density readings and Soil Stiffness Gauge measurements were conducted by WisDOT central office staff.

Initial subgrade deflection testing was completed on May 31, 2001 and included the eastern portion of Silvernail Road, which is the southern frontage road to I-94. Subgrade testing included coverages along 4 lines representing the projected locations of the travel lanes after pavement construction. Initial zeroing runs were conducted along portions of the paved park and ride lot located near the CTH G interchange. The quad-axle truck was loaded to a gross loading of 73,260 lb with 27,460 lb distributed over the front axle.

Figures 2.1.1 through 2.1.12 illustrate the collected deflection profiles normalized to a front axle loading of 24,000 lb. For each line of testing, subgrade deflections produced by the front tires of the quad-axle truck are presented in two formats: 1) using baseline readings of pre-loaded surface profile as measured by the front bumper-mounted sensors , and 2) using only the axle-mounted sensors. **Figures 2.1.13 through 2.1.23** illustrate the results of DCP testing conducted at selected locations. **Table 2.1.1** provides comparative test data for those locations where nuclear and soil stiffness gauge tests were performed.

A second round of subgrade deflection testing was completed on June 28, 2001 and included portions of the eastbound ramps and a small section of CTH SS just south of the new structure. Subgrade testing along the ramps included coverages along 2 lines either side of the projected centerline of the pavement after construction. Subgrade testing along CTH SS included 3 coverages along lines of the projected centerline of the pavement after construction. Initial zeroing runs were conducted along portions of the paved park and ride lot located near the CTH G interchange. The quad-axle truck was loaded to a gross loading of 73,280 lb with 26,180 lb distributed over the front axle.

Figures 2.1.24 through 2.1.39 illustrate the collected deflection profiles normalized to a front axle loading of 24,000 lb. For each line of testing, subgrade deflections produced by the front tires of the quad-axle truck are presented in two formats: 1) using baseline readings of pre-loaded surface profile as measured by the front bumper-mounted sensors , and 2) using only the axle-mounted sensors. **Figures 2.1.40 through 2.1.49** illustrate the results of DCP testing conducted at selected locations. **Table 2.1.2** provides comparative test data for those locations where nuclear and soil stiffness gauge tests were performed.

A final round of subgrade deflection testing was completed on July 7, 2001 and included portions of the westbound ramps. Subgrade testing along the ramps included coverages along 2 lines either side of the projected centerline of the pavement after construction. Initial zeroing runs were conducted along portions of Golf Road west of the CTH G interchange. The quad-axle truck was loaded to a gross loading of 73,680 lb with 24,820 lb distributed over the front axle.

Figures 2.1.50 through 2.1.59 illustrate the collected deflection profiles normalized to a front axle loading of 24,000 lb. For each line of testing, subgrade deflections produced by the front tires of the quad-axle truck are presented in two formats: 1) using baseline readings of pre-loaded surface profile as measured by the front bumper-mounted sensors , and 2) using only the axle-mounted sensors. **Figures 2.1.60 through 2.1.64** illustrate the results of DCP testing conducted at selected locations. **Table 2.1.3** provides comparative test data for those locations where nuclear and soil stiffness gauge tests were performed.

2.2 STH 57 - Ozaukee County

Subgrade deflection tests were conducted in July 7, 2001 along a portion of subgrade being constructed as new alignment for STH 57, just north of CTH A in Fredonia, under project ID 4015-00-70. Tests were conducted in a predominant fill section with the loaded quad-axle truck supplied by Michels pulling the RWD. The quad-axle truck was loaded to a gross load of 73,680 lb with a load of 24,820 lb distributed on the front axle. Two passes were made along the centerline of the projected pavement. Comparative DCP testing was conducted at selected subgrade locations by Marquette staff. Nuclear gauge and soil stiffness gauge testing was performed by WisDOT central office staff.

Figures 2.2.1 through 2.2.2 illustrate the collected deflection profiles of the RWD at a single wheel load of 12,000 lb. **Figures 2.2.3 through 2.2.8** illustrate the collected deflection profiles of the quad-axle truck with the load normalized to a front axle loading of 24,000 lb. For each line of testing, subgrade deflections produced by the front tires of the quad-axle truck are presented in two formats: 1) using baseline readings of pre-loaded surface profile as measured by the front bumper-mounted sensors , and 2) using only the axle-mounted sensors. **Figures 2.2.9 through 2.2.12** illustrate comparative deflections obtained with the RWD and the quad-axle dump truck. **Figures 2.2.13 through 2.2.31** illustrate the results of DCP testing conducted at selected locations. **Table 2.2.1** provides comparative test data for those locations where nuclear and soil stiffness gauge tests were performed.

2.3 USH 41 - Oconto County

Subgrade deflection tests were conducted on August 31, 2001 and again on September 27, 2001 during the construction of frontage roads and cross-road fills under Project ID 1152-07-75. Comparative DCP testing was also conducted at selected locations by Marquette staff.

Nuclear density readings were conducted by WisDOT D-3 staff at selected locations.

Subgrade deflection tests conducted on August 31, 2001 utilized only the quad-axle truck supplied by Michels which was loaded to a gross weight of 73,100 lb with a load of 25,000 distributed on the front axle. Tests were conducted over sections of the east and west frontage roads as well as over sections of the Sampson and Oak Orchard cross-roads. Zero runs were conducted over a paved portion of the west frontage road. **Figures 2.3.1 through 2.3.16** illustrate the collected deflection profiles of the quad-axle truck with the load normalized to a front axle loading of 24,000 lb. For each line of testing, subgrade deflections produced by the front tires of the quad-axle truck are presented in two formats: 1) using baseline readings of pre-loaded surface profile as measured by the front bumper-mounted sensors , and 2) using only the axle-mounted sensors. For an unknown reason, one of the bumper mounted sensors in the left wheel track was inoperable during all but the zero run. Therefore, only calculated wheel values in the right wheel track are provided in these figures. **Figures 2.3.17 through 2.3.36** illustrate the results of DCP testing conducted at selected locations. **Table 2.3.1** provides comparative test data for those locations where nuclear and/or DCP tests were performed.

A second round of subgrade deflection tests was conducted on September 27, 2001 with the loaded quad-axle truck supplied by Michels pulling the RWD. The quad-axle truck was loaded to a gross load of 72,500 lb with a load of 24,100 lb distributed on the front axle. Tests were conducted over portions of the east frontage road and the Geano Beach cross-road. Zero runs were conducted over a paved portion of the east frontage road.

Figures 2.3.37 through 2.3.41 illustrate the collected deflection profiles of the RWD at a single wheel load of 12,000 lb. **Figures 2.3.42 through 2.3.53** illustrate the collected deflection profiles of the quad-axle truck with the load normalized to a front axle loading of 24,000 lb. **Figures 2.3.54 through 2.3.63** illustrate comparative deflections obtained with the RWD and the quad-axle dump truck. **Figures 2.3.64 through 2.3.73** illustrate the results of DCP testing conducted at selected locations. **Table 2.3.2** provides comparative test data for those locations where nuclear density and/or CBR tests were performed.

2.4 STH 57 - Sheboygan County

Subgrade deflection tests were conducted on September 4, 2001 and again on September 28, 2001 July, 2000 during the construction of the new northbound lanes of STH 57 under Project ID 4015-08-71. Comparative DCP testing was also conducted at selected locations by Marquette staff. Nuclear density readings were conducted by WisDOT D-3 staff at selected locations.

Subgrade deflection tests conducted on September 4, 2001 included variable cut and fill sections located just north of CTH D . Tests were conducted with the loaded quad-axle truck supplied by Michels pulling the RWD. The quad-axle truck was loaded to a gross load of 71,800 lb with a load of 23,980 lb distributed on the front axle. Two passes were made along the centerline of the projected pavement. Comparative DCP testing was conducted at selected subgrade locations by Marquette staff. Nuclear gauge and soil stiffness gauge testing was performed by WisDOT D-3 personnel.

Figures 2.4.1 and 2.4.2 illustrate the collected deflection profiles of the RWD at a single wheel load of 12,000 lb. **Figures 2.4.3 and 2.4.4** illustrate the collected deflection profiles of the quad-axle truck with the load normalized to a front axle loading of 24,000 lb. **Figures 2.4.5 and 2.4.6** illustrate comparative deflections obtained with the RWD and the quad-axle dump truck. **Figures 2.4.7 through 2.4.10** illustrate the results of DCP testing conducted at selected locations. **Table 2.4.1** provides comparative test data for those locations where nuclear density and/or CBR tests were performed.

The second round of subgrade deflection tests were conducted on September 28, 2001 included predominant fill sections located between Knuth and Knorr Roads. Tests were conducted with the loaded quad-axle truck supplied by Michels pulling the RWD. The quad-axle truck was loaded to a gross load of 72,500 lb with a load of 24,100 lb distributed on the front axle. Two passes were made along the centerline of the projected pavement. Comparative DCP testing was conducted at selected subgrade locations by Marquette staff. Nuclear gauge and soil stiffness gauge testing was performed by WisDOT D-3 personnel.

Figures 2.4.11 and 2.4.12 illustrate the collected deflection profiles of the RWD at a single wheel load of 12,000 lb. **Figures 2.4.13 through 2.4.18** illustrate the collected deflection profiles of the quad-axle truck with the load normalized to a front axle loading of 24,000 lb. **Figures 2.4.19 through 2.4.22** illustrate comparative deflections obtained with the RWD and the quad-axle dump truck. **Figures 2.4.23 through 2.4.25** illustrate the results of DCP testing conducted at selected locations. **Table 2.4.2** provides comparative test data for those locations where nuclear density and/or CBR tests were performed.

2.5 Discussion of Field Test Results

The deflection data collected during this study phase with the loaded quad-axle dump truck indicates that the shortening of the front sensor rack to ensure that no side extensions exist has resulted in a data bias due to swaying of the front bumper. Observation of zeroing runs conducted on most projects indicate an oscillation of the zero readings when the reference deflections measured by the front rack are incorporated into the calculation of wheel deflections. This oscillation is most likely the results of slight side pitching of the body during travel and is essentially removed when only the axle readings are utilized. When compared to RWD deflections measured during comparative testing, deflections computed using only the axle readings are also in better agreement. For this reason, all deflection comparisons to the loaded quad-axle truck (truck-RWD, truck-CBR, truck-"failed" locations) are based on axle only deflection results. Loaded truck wheel deflections, calculated using the front sensor rack reference, are provided in graphical format for comparison.

When viewed in the context of deflection acceptance testing, the use of axle-only deflections inhibit the correction for uneven surface profiles existing prior to actual testing. However, if the subgrade surface is properly bladed and rolled prior to the start of testing, a condition which is specified at the end of each working day, minor irregularities in the subgrade surface should have only localized effects.

The comparative data collected from deflection testing, DCP, nuclear gauge and soil stiffness gauge is presented in tabular form for each project in **Tables 2.1.1 through 2.4.2**. Direct comparison between measured deflection and in-place CBR are difficult to present due to the variability in CBR values with depth. Additionally, many of the test locations encountered during pilot implementation were composed of soils with numerous inclusions of cobble or larger sized stones at varying depths which prevented penetration of the DCP rod and made characterization of the in-place CBR impossible. For the purposes of deflection-CBR comparisons in this report, collected DCP data was segregated based on the 6 inch depth zones where CBRs of 6 or less were obtained within the top 24 inches of the completed grade. This resulted in 7 potential comparative conditions as follows:

1. CBR 6 or less only in top 6 inches
2. CBR 6 or less only between 6 - 12 inches below the surface
3. CBR 6 or less only between 12 - 18 inches below the surface
4. CBR 6 or less only between 18 - 24 inches below the surface
5. CBR 6 or less only between 0 - 12 inches below the surface
6. CBR 6 or less only between 12 - 24 inches below the surface
7. CBR 6 or less from 0 - 24 inches below the surface

Table 2.5.1 provides comparative CBR and deflection readings obtained within approximately +/- 5 feet from the DCP test location differentiated by the above 7 CBR condition states. Examination of this comparative data indicates that measured deflections are most notably affected by low CBR readings within the upper 12 inches. This trend is similar to those observed during previous study phases and indicates that differentiation of locations with weak soils using only surface deflections may be difficult if the weakness occurs only below depths of approximately 12 inches.

Figures 2.5.1 and 2.5.2 illustrate comparative plots of calculated CBR versus Soil Stiffness for test projects within District 2. **Figure 2.5.3** illustrates maximum recorded deflections versus Soil Stiffness for these projects. As shown, there is significant scatter in the data sets making useful correlations difficult. **Figures 2.5.4 and 2.5.5** illustrate maximum recorded deflections vs calculated CBR for all District 2 projects. While there is still considerable scatter in the data, the trending of deflection data is more evident in these plots. **Figure 2.5.6** provides a comparative deflection versus CBR plot for all 2001 pilot projects and previous 2000 test projects. Based on verbal and/or written communication from WisDOT observers of the pilot deflection testing, **Table 2.5.2** was prepared to provide comparative deflection readings obtained in areas considered as "failed". Provided are both the average deflections and maximum deflections obtained within the "failed" limits. In some instances, the observers noted localized areas, which when considered alone would have been considered as failed but when viewed in the context of requiring corrective actions, none would have been specified.

In an effort to develop more meaningful deflection trends over pilot projects tested in passing and failing grade locations, the collected deflection data was further analyzed to develop block average deflection readings obtained over successive 5 foot (1.5 meter) test increments. This block averaging method was selected as a practical means for processing deflection data on test projects. Cumulative frequency plots of collected deflections in passing and failed areas were then developed from the block averages. **Figures 2.5.7 through 2.5.9** illustrate cumulate frequency plots for the collected RWD deflection data for each included test project. Figure 2.5.10 provides an overall combined cumulative frequency plot for all collected RWD test data. Figures of this type can be utilized to select a deflection acceptance threshold which limits associated acceptance errors to tolerable values. Due to the overlap in the cumulative frequency lines shown in Figures **2.5.8 through 2.5.10**, it is not possible to establish any reasonable deflection threshold which does not include an associated acceptance error, i.e, for any selected deflection acceptance threshold value, some passing grade would be rejected (Type 1 error) and some failing grade would have been accepted (Type 2 Error).

For example, using the results illustrated in **Figure 2.5.10** a selected RWD deflection acceptance threshold of 1.5 inches would imply that approximately 7% of the tested grade which was visually passed would have been rejected and approximately 24% of the tested grade which was failed would have been accepted. Similarly, if a Type 1 error of 10% maximum is selected, the corresponding deflection acceptance threshold from **Figure 2.5.10** would be approximately 1.25 inches and the probability of an associated Type 2 error would be approximately 12.5%.

Figures 2.5.11 through 2.5.14 illustrate cumulative frequency plots for the collected quad-axle truck data for each included project. **Figure 2.5.15** provides an overall combined cumulative frequency plot for all collected quad-axle truck data. Based on the results

illustrated in **Figure 2.1.15**, associated Type 1 and Type 2 errors were developed for a range of deflection acceptance thresholds and are provided in
Table 2.5.3.

Based on the comparative results provided, particularly those provided in **Table 2.5.3**, a deflection acceptance threshold of 1.50 inches for the loaded quad-axle truck is recommended, which equates to a probability of a Type 1 error of 7.7% and a Type 2 error of 42.8%.

3.0 DEFLECTION ACCEPTANCE CRITERIA

The results of study Phases I through III recommended the development of deflection acceptance criteria based on in-place subgrade stability as defined by the soil CBR value. A soil CBR value of 6 was selected to represent the lower threshold of soil strength required to provide an adequate construction platform and limit subgrade rutting. CBR values in excess of 6 should be readily achieved for many soil types if proper compaction techniques are followed. For these soils, lowering the threshold of acceptability may defeat the purpose of the specifications and result in completed grades with stabilities far below designer's expectations. On the other hand, lower stiffness soils which are expected to have CBR values in the range of 6 - 10 after proper compaction may be considered as better candidates for acceptance testing to ensure the desired minimal strength is achieved.

The above discussion illustrates the challenge of developing deflection-based acceptance criterion that will adequately cover the full range of soil strength variations that may be encountered in the field. The trends of deflection versus in-place CBR developed from this study indicate that subgrade deflection measurements under controlled loading conditions may be useful for identifying test locations where in-place strength is adequate for construction operations, provided those operations occur without significant moisture change in the soils. However, unless the moisture sensitivity of the soils has been established and proper moisture controls have been effected during construction, any soil strength measure can be viewed as transient and adverse changes in strength may result.

It is recommended that Year 2002 project implementations of the deflection acceptance specifications, if conducted, be targeted to projects where moisture sensitive silts and clays are anticipated to be in place within the upper 24 inches of completed grades. A deflection acceptance threshold of 1.50 inches under a standard front axle loading of 24,000 lb (single wheel loading of 12,000 lb) is recommended for use during testing of completed grades. At this time it is recommended that deflection acceptance testing not be conducted on intermediate lifts as the requirements for internal stability within these zones are significantly different than those required for subsequent pavement construction activities.

3.1 Deflection Testing Equipment

Experiences gained during the conduct of deflection testing during the pilot implementations indicate that the use of a fully loaded quad-axle dump truck is the most practical means for performing deflection acceptance testing. Based on the observed sequencing of construction, the locations of completed grade ready for testing, the availability of access routes to completed grades, and the availability of adequate turn-around locations, the use of the RWD would be problematic in many instances. With only one such system in existence, its limited availability and set-up requirements for water ballasting would also pose significant scheduling difficulties.

While not the case for every data set, the good agreement between deflections measured by axle-mounted sensors on the quad-axle dump truck and the RWD is observable in the comparison figures and tables developed from the pilot implementations. For the purposes of specification implementations during the 2002 construction season, it is recommended that the quad-axle truck with the simplified configuration, using only two axle mounted sensors, be utilized. The deflection sensors should be located 2 feet inward from each tire center to provide profile measurements of each wheel track. This would result in a instrumentation configuration which could easily be field-installed in 5 minutes or less. With proper protection from the elements, it is possible to leave the sensors in place during normal usage of the truck so that only protective covers need to be removed prior to testing.

It is further recommended that the marking system used to paint locations where acceptance thresholds are exceeded be configured such that only one mark is applied, representing one or both wheel paths where thresholds are exceeded. This system could be easily adapted to the driver's side step grate, making it more visible to the operator during testing. For the vast majority of cases observed during pilot testing, locations of high deflection and permanent rutting were either similar within wheel paths or easily discernable if differences existed. Furthermore, if conditions were such that differentiation between wheel paths was difficult in the field, the summary printout from the deflection run would clearly identify which wheel path exceeded the acceptance threshold.

It is recommended that Year 2002 implementations of the deflection acceptance specifications utilize the following guidelines for truck instrumentation:

1. The dump truck should be loaded to a sufficient gross load to produce a distributed front axle loading of 24,000 lbs (+/- 500 lb) with the pusher axles raised. Total load as well as front axle loading should be verified by a certified weigh ticket.

2. Front axle flotation tires, which are normally G286 super single tires inflated to 110 - 125 psi cold, should be specified.

3. WisDOT approved deflection instrumentation should be mounted in such a way as to provide recordation of both front tire wheel tracks. A total of two front axle-mounted sensors are required, with sensors mounted 2 ft inward of the centerline of both front tires.

4. A distance measuring device, composed of a proximity sensor and targets, must be provided on the truck to produce pulse voltages of 0 - 5 volts at a travel interval not to exceed 1 ft. The proximity sensor targets may be mounted on the circumference of the drive shaft or on one of the truck tires, provided that the firing interval of the proximity sensor is consistent for all driving surfaces.

5. A positive marking system should be mounted to the front bumper or the step grate to provide surface marks indicating locations where wheel deflections exceed threshold values. The system should apply an easily visible paint or chalk line to the surface of the tested subgrade regardless of subgrade moisture conditions existing at the time of testing.

6. A WisDOT approved data processing/storage device shall be mounted in a location which is readily accessible to the 12 volt DC power source of the truck.

3..2 Deflection Testing Pattern

It is recommended that deflection tests be conducted over the full-width of the constructed subgrade as defined by the edge limits of the proposed pavement shoulders. Tests should be conducted with a minimum of one pass of the loaded truck along each shoulder and proposed driving lane. For two-lane roadways, this pattern would result in a minimum of four passes (one for each lane and one for each shoulder). Deflection testing should be performed at normal walking speeds not to exceed 5 mph nor be less than 2.5 mph. Deflection testing should completed with the pusher axles raised during testing, i.e., all load carried only by the front steering axle and the rear tandem axle group.

Deflection testing should be conducted as soon as practical after final subgrade elevation has been reached so that significant moisture loss from the subgrade would not bias the deflection results.

3.3 Deflection Acceptance Criteria

Based on the deflection data gathered during this research study from test areas which were considered as passing based on visual observations, a deflection acceptance threshold of 1.50 inches appears reasonable to limit associated Type 1 and Type 2 errors. For use within Year 2002 implementations, this threshold value is recommended for use to identify potentially "failed" test locations. The project engineer should retain the right to require corrective actions to improve subgrade conditions based on the magnitude and extent of failed readings.

Previous study phase reports have indicated the need to conduct DCP testing in failed areas to determine the severity and depth of weak subgrades. While data obtained from this type of testing has been helpful in developing the recommendations contained herein, the use of DCP testing in failed areas should not be required, but rather left to the contractor's discretion to aid in the development of potential corrective actions.

3.4 Recommended Supplemental Tests

For those projects selected for Year 2002 specification implementation, it is recommended that laboratory testing be conducted for those soils proposed for use in construction to establish moisture-density and compacted strength profiles for soaked and unsoaked specimens. These results would be available for review by WisDOT and contractor personnel to ensure that agency expectations would be clearly enumerated. During subgrade construction, it is also recommended that soil moisture contents be monitored, particularly in the upper 24 inches, to ensure that compaction moisture contents are within acceptable limits of the optimum moisture content for that soil, which is typically +/- 10% of the optimum moisture content. The conduct of the above laboratory tests and soil moisture measurements are not required to implement deflection acceptance testing; rather, these measures are recommended to provide more information to assess the deflection testing process.

Prior to the conduct of deflection acceptance testing, system validation runs are recommended to ensure the integrity of the sensors and distance measuring device. A static calibration check of each deflection sensor should be conducted prior to actual subgrade deflection testing to ensure that the magnitude of deflection readings are within tolerance. This is easily accomplished by placing a calibration block of known thickness under each sensor and verifying that the recorded deflection matches the block thickness to a tolerance of +/- 0.025 inches. A zeroing validation of the sensors should also be completed by driving the fully loaded truck over a smooth, paved surface of sufficient structure to be considered as "unyielding". The minimum travel distance should be 1000 times the firing interval of the distance measuring device. It is recommended that at least two zeroing runs be conducted, i.e. up and down a pre-marked location, to confirm deflection sensor and distance measuring systems are within tolerance, typically +/- 0.10 inches for deflections and +/- 0.1% for DMI values.

4.0 SUMMARY AND RECOMMENDATIONS

This report has presented the findings of implementations of pilot specifications for subgrade acceptance based on measured deflections. The reconfigured rolling wheel deflectomter (RWD), portable truck-mounted deflection measurement systems, and dynamic cone penetrometer (DCP) were utilized on four subgrade construction projects during the 2001 construction season. Comparative nuclear density readings were obtained at selected locations within each project. Comparative soil stiffness gauge readings were also obtained on 2 of the pilot projects

The research findings from this and previous study phases indicate that deflection test results may be appropriate for identifying areas of poor in-place stability within constructed subgrades. However, deflection testing alone may not provide all of the data necessary to properly differentiate acceptable and non-acceptable subgrade stabilities. It is important to note that deflection test results are related to the moisture-density conditions at the time of testing. Soils that show acceptable results (i.e., low deflections) may subsequently weaken due to changes in moisture content, freezing/thawing, etc. In instances where subgrade acceptance is well in advance of base course application, subgrade moisture changes may result in decreased soil support. For those conditions where soil compaction has been conducted at a moisture state near optimum, surface deflections should be correlated to the achieved level of compaction.

The overall objectives of this research have been met and useful correlations between subgrade deflections and in-place subgrade stability, as measured by the California Bearing Ratio (CBR) or interpreted by visual observations, have been developed. Deflection data collected to date using instrumentation on the axles of loaded quad-axle trucks indicates this data source is adequate for the identification of areas that need further evaluation by WisDOT and contractor personnel to determine if corrective actions are warranted. It is recommended that implementations of deflection acceptance testing be conducted during the 2002 construction season, if possible, on selected projects where moisture sensitive soils are anticipated.

Table 2.1.1: Comparative Field Test Data for CTH SS - Waukesha County, May 31, 2001

Test Location		Nuclear Tests		Soil Stiffness Gauge (3) Young's Modulus (ksi) / Stiffness (klbf.in)						In-Place CBR (4)				Average Deflection (inch) (5)	
Station	Offset	% Rel Comp(1)	% Opt Moist (2)	1		2		3		0-6	6-12	12-18	18-24	Right	Left
20+447.3	2.13m R	97.8	88.5	5.6	25.3	6.0	27.3	**7.8**	**35.2**	10	10	7	3	1.78	3.40
20+468.9	0.61m L	107.6	51.0	13.1	59.5	8.8	39.9	**16.0**	**72.8**	32	52	59	na	0.58	0.44
20+494.4	1.68m R	80.1	218.3	**10.3**	**46.8**	8.4	38.1	9.4	42.5	7	2	4	7	1.81	1.18
20+523.1	2.31m R	89.2	142.3	6.1	27.8	**12.0**	**54.4**	**10.7**	**48.6**	13	27	46	na	0.89	0.66
20+523.1	1.22m L	103.2	80.8	6.6	29.8	5.5	24.9	5.8	26.1	16	na	na	na	0.59	1.01
20+523.1	6.91m L	85.1	160.6	8.5	38.7	5.9	26.6	7.6	34.6	3	4	2	3	3.39	1.19
20+540.0	5.49m L	107.6	44.2	14.3	64.7	14.4	35.4	14.0	63.5	na	na	na	na	-0.05	0.05
20+540.0	0.00m R	92.8	113.5	8.1	36.7	**11.0**	**50.1**	7.0	31.8	24	63	na	na	0.86	0.67
20+540.0	4.82m R	93.5	139.4	7.3	33.2	12.3	55.9	10.2	46.2	17	25	na	na	0.65	1.17
20+574.3	0.00m R	106.8	82.7	9.1	41.3	11.8	53.5	16.8	76.1	29	na	na	na	0.30	0.35
20+574.3	4.27m L	96.7	116.3	9.4	42.6	10.5	47.5	9.5	43.3	4	11	na	na	4.03	3.49

(1) Maximum Dry Density = 126.5 pcf
(2) Optimum Moisture Content = 10.4%
(3) Bold values performed in wheel ruts
(4) Results marked na (not available) are due to cobble obstructions which resisted penetration
(5) Deflections from axle sensors only average over 5 feet around test location

Table 2.1.2: Comparative Field Test Data for CTH SS - Waukesha County, June 28, 2001

Test Location		Nuclear Tests		Soil Stiffness Gauge Young's Modulus (ksi) / Stiffness (klbf.in)						In-Place CBR [3]				Average Deflection (inch) [4]	
Station	Offset	% Rel Comp[1]	% Opt Moist [2]	1		2		3		0-6	6-12	12-18	18-24	Right	Left
36+040	2.4m R	99.8	38.5	10.1	45.6	9.8	44.2	9.4	42.8	10	7	6	14	1.06	0.33
36+060	2.4m R	112.9	35.6	13.5	61.2	10.9	49.5	11.4	51.6	na	na	na	na	0.45	0.50
36+080	2.4m R	107.7	60.6	10.0	45.1	11.4	51.8	7.8	35.4	na	na	na	na	1.47	0.97
36+100	2.4m R	106.7	56.7	9.7	44.0	8.9	40.3	10.4	47.2	7	44	46	na	0.61	0.50
36+140	2.4m R	90.9	25.0	7.5	33.8	7.8	35.1	6.8	30.6	11	32	46	19	0.78	0.57
36+180	2.4m R	90.4	65.4	8.7	39.4	10.1	45.7	9.1	41.2	na	na	na	na	1.28	1.04
36+180	2.4m L	91.1	90.4	11.2	50.6	12.5	56.7	12.2	55.2	na	na	na	na	0.03	0.27
36+140	2.4m L	94.2	57.7	7.6	34.6	7.9	36.0	7.7	35.0	22	36	na	na	0.55	0.45
36+100	2.4m L	110.9	48.1	7.1	32.3	8.0	36.1	6.9	31.2	11	11	29	25	1.05	0.96

(1) Maximum Dry Density = 126.5 pcf
(2) Optimum Moisture Content = 10.4%
(3) Results marked na (not available) are due to cobble obstructions which resisted penetration
(4 Deflections from axle sensors only average over 5 feet around test location

Table 2.1.2 (Cont.): Comparative Field Test Data for CTH SS - Waukesha County, June 28, 2001

Test Location		Nuclear Tests		Soil Stiffness Gauge Young's Modulus (ksi) / Stiffness (klbf.in)						In-Place CBR [3]				Average Deflection (inch) [4]	
Station	Offset	% Rel Comp[1]	% Opt Moist [2]	1		2		3		0-6	6-12	12-18	18-24	Right	Left
36+060	2.4m L	102.1	54.8	9.6	43.3	9.1	41.2	7.8	35.4	6	20	14	14	1.74	1.88
0+980	10.7m R	99.4	81.7	10.8	48.8	8.8	39.9	9.7	44.2	3	14	20	24	2.54	1.16
0+968	10.7m L	94.3	78.8	7.0	31.6	6.2	28.2	9.7	43.9	3	14	20	24	1.69	2.89
35+740	2.4m R	97.5	47.1	8.5	38.5	8.9	40.4	8.5	38.7	na	na	na	na	0.47	0.77
35+740	2.4m L	95.7	45.2	9.1	41.3	5.4	24.3	5.0	22.6	na	na	na	na	0.88	0.88
35+780	2.4m L	94.4	65.4	6.5	29.6	6.2	28.4	9.6	43.3	na	na	na	na	0.53	0.30
35+780	2.4m R	93.4	59.6	8.3	37.4	8.0	36.2	8.7	39.3	na	na	na	na	0.51	0.29
35+820	2.4m R	93.1	32.7	6.2	28.0	6.2	27.9	6.2	28.4	na	na	na	na	1.26	0.47
35+820	2.4m L	93.3	27.9	5.6	25.5	5.6	25.2	5.4	24.7	6	19	49	na	1.19	0.87

(1) Maximum Dry Density = 126.5 pcf
(2) Optimum Moisture Content = 10.4%
(3) Results marked na (not available) are due to cobble obstructions which resisted penetration
(4) Deflections from axle sensors only average over 5 feet around test location

Table 2.1.3: Comparative Field Test Data for CTH SS - Waukesha County, July 11, 2001

Test Location		Nuclear Tests		Soil Stiffness Gauge (3) Young's Modulus (ksi) / Stiffness (klbf.in)						In-Place CBR (4)				Average Deflection (inch) (5)	
Station	Offset	% Rel Comp(1)	% Opt Moist (2)	1		2		3		0-6	6-12	12-18	18-24	Right	Left
35+980	1.8m R	110.6	47.1	6.4	28.8	10.0	45.6	13.6	61.6	na	na	na	na	0.21	0.26
35+980	1.8m L	106.6	34.6	10.3	46.8	10.8	49.2	10.0	45.3	na	na	na	na	-0.81	-0.24
36+060	2.4m L	111.6	45.2	11.0	50.1	9.7	44.0	13.8	62.7	7	17	13	4	**0.90**	**1.51**
36+060	4.3m R	109.3	60.6	6.7	30.5	7.2	32.6	6.4	29.2	7	17	13	4	0.62	0.41
36+120	6.1m R	113.2	51.9	7.8	35.5	9.9	45.0	5.7	25.8	7	19	8	na	**1.31**	**1.36**
36+120	2.4m L	113.0	40.4	10.5	47.7	11.1	50.4	11.6	52.6	20	41	39	na	**1.36**	**1.33**
35+852	2.7m L	103.7	42.3	6.3	28.5	6.3	28.7	7.0	31.8	na	na	na	na	0.38	0.43
35+780	2.4m L	107.4	43.3	7.9	35.9	7.8	35.4	7.2	32.8	na	na	na	na	0.63	0.57

(1) Maximum Dry Density = 126.5 pcf
(2) Optimum Moisture Content = 10.4%
(3) Bold values performed in wheel ruts
(4) Results marked na (not available) are due to cobble obstructions which resisted penetration
(5) Deflections from axle sensors only average over 5 feet around test location. Bold values are in sections "failed" by WisDOT observers.

Table 2.2.1: Comparative Field Test Data for STH 57 - Ozaukee County, July 11, 2001

Test Location		Nuclear Tests		Soil Stiffness Gauge Young's Modulus (ksi) / Stiffness (klbf.in)						In-Place CBR [3]				Average Deflection (inch) [4]		
Station	Offset	% Rel Comp[1]	% Opt Moist [2]	1		2		3		0-6	6-12	12-18	18-24	RWD	Truck Right	Truck Left
12+880	1.8m L	91.9	107.7	15.3	69.4	12.1	55.0	14.1	63.9	39	17	6	7	1.02	0.15	0.01
12+880	1.8m R	97.5	90.4	13.3	60.5	12.5	56.8	14.1	64.2	29	8	10	19	0.73	0.13	-0.03
12+720	1.8m R	99.4	77.9	10.1	45.9	14.9	67.5	11.4	51.5	na	na	na	na	1.10	-0.07	0.30
12+560	1.8m R	96.7	87.5	8.4	38.2	11.3	51.1	12.2	55.3	14	11	6	6	1.38	0.73	-0.12
12+400	1.8m R	98.0	80.8	10.6	48.0	11.1	50.5	14.7	66.6	61	17	6	6	1.11	0.65	0.58
12+240	1.8m R	87.9	110.6	10.4	47.3	12.3	55.8	12.1	54.9	16	7	4	6	0.90	-0.31	0.04
12+240	1.8m L	94.2	84.6	7.4	33.5	10.2	46.4	11.2	50.6	10	3	3	4	2.07	1.04	0.51
12+720	1.8m L	100.6	87.5	12.4	56.0	10.8	49.2	13.0	59.0	na	na	na	na	0.94	0.18	0.12

(1) Maximum Dry Density = 126.5 pcf based on CTH SS sample
(2) Optimum Moisture Content = 10.4% based on CTH SS sample
(3) Results marked na (not available) are due to cobble obstructions which resisted penetration
(4) Deflections from axle sensors only average over 5 feet around test location. Bold values are in sections "failed" by WisDOT observers.

Table 2.2.1 (Cont.): Comparative Field Test Data for STH 57 - Ozaukee County, July 11, 2001

Test Location		Nuclear Tests		Soil Stiffness Gauge Young's Modulus (ksi) / Stiffness (klbf.in)						In-Place CBR [3]				Average Deflection (inch) [4]		
Station	Offset	% Rel Comp[1]	% Opt Moist [2]	1		2		3		0-6	6-12	12-18	18-24	RWD	Truck Right	Truck Left
12+560	1.8m L	98.3	84.6	12.0	54.3	10.4	47.0	13.6	61.7	20	17	11	6	0.40	0.70	0.40
12+400	1.8m L	97.4	97.1	9.7	44.1	9.3	42.2	12.9	58.5	61	17	6	6	0.30	0.97	0.36
12+080	1.8m L	100.5	72.1	13.0	58.8	12.1	55.0	13.5	61.1	na	na	na	na	0.52	0.61	0.26
12+080	1.8m R	100.1	65.4	11.9	53.8	9.4	42.8	11.0	49.7	na	na	na	na	0.62	0.78	0.94
11+920	1.8m L	99.8	80.8	11.0	50.0	13.4	60.8	11.1	50.4	na	na	na	na	0.48	0.86	0.61
11+920	1.8m R	100.3	66.3	10.1	45.9	7.8	35.4	13.8	62.4	na	na	na	na	0.53	0.72	0.49
11+760	1.8m L	96.3	96.2	8.5	38.4	8.9	40.3	9.6	43.6	na	na	na	na	0.66	0.72	0.48
11+760	1.8m R	99.4	69.2	12.0	54.2	12.4	56.2	13.5	61.4	na	na	na	na	0.39	0.97	0.44

(1) Maximum Dry Density = 126.5 pcf based on CTH SS sample
(2) Optimum Moisture Content = 10.4% based on CTH SS sample
(3) Results marked na (not available) are due to cobble obstructions which resisted penetration
(4) Deflections from axle sensors only average over 5 feet around test location. Bold values are in sections "failed" by WisDOT observers.

Table 2.3.1: Comparative Field Test Data for USH 41 - Oconto County, August 31, 2001

Test Location			Nuclear Tests		In-Place CBR [6]				Average Truck Deflection, inch	
Station	Offset	Location	% Rel Comp	% Opt Moist	0-6	6-12	12-18	18-24	Right	Left
15+320	3m R	West Frontage [1]	91.4	63.7	20	24	20	16	-0.15	0.02
15+520	0m R	West Frontage [1]	100.0	112.9	16	7	7	14	0.29	0.93
15+640	2m L	West Frontage [1]	102.1	95.0	17	10	14	11	0.38	0.67
16+360	2m L	West Frontage [2]	101.0	100.0	7	4	6	4	**2.01**	**2.42**
4+160	1m R	Sampson Road [3]	108.2	61.6	29	16	na	na	0.02	0.09
4+287	0m R	Sampson Road [3]	102.5	85.5	8	3	4	4	**0.86**	**0.64**
17+720	0m R	East Frontage [4]	102.1	130.1	20	11	16	25	0.97	1.13
4+186	1m R	Oak Orchard [5]	101.3	74.2	10	10	13	17	1.52	0.57

(1) Proctor results = 126.5 pcf max dry density @ 7.0% optimum moisture
(2) Proctor results = 124.2 pcf max dry density @ 10.4% optimum moisture
(3) Proctor results = 135.2 pcf max dry density @ 7.6% optimum moisture
(4) Based on 127.0 pcf max dry density @ 7.0% optimum moisture
(5) Based on 125.0 pcf max dry density @ 10.4% optimum moisture
(6) Results marked na (not available) are due to cobble obstructions which resisted penetration
(7) Deflections from axle sensors only average over 5 feet around test location. Bold values are in sections "failed" by WisDOT observers.

Table 2.3.2: Comparative Field Test Data for USH 41 - Oconto County, September 27, 2001

Test Location			Nuclear Tests		In-Place CBR				Average Deflection, inch (3)		
Station	Offset	Location	% Rel Comp	% Opt Moist	0-6	6-12	12-18	18-24	RWD	Truck	
										Right	Left
16+868	0.3m R	East Frontage (1)	96.6	83.3	7	6	4	16	2.30	2.47	1.65
16+800		East Frontage	na	na	10	25	25	20	1.15	0.59	0.87
16+430	2m R	East Frontage (1)	100.1	67.9	7	7	16	8	1.60	2.57	2.09
16+520	3m R	East Frontage (1)	96.9	100.0	1	7	19	14	2.97	2.53	1.75
4+255	4m R	Geano Beach (2)	90.1	67.9	8	16	13	7	**0.25**	0.48	1.26
4+200		Geano Beach	na	na	4	14	8	29	1.38	1.39	2.00

(1) Proctor results = 140.0 pcf max dry density @ 8.4% optimum moisture
(2) Based on 140.0 pcf max dry density @ 8.4% optimum moisture
(3) Deflections from axle sensors only average over 5 feet around test location.

Table 2.4.1: Comparative Field Test Data for STH 57 - Sheboygan County, September 4, 2001

Test Location		Nuclear Tests			In-Place CBR				Average Deflection, inch (3)		
Station	Offset	% Rel Comp	% Moist Content	% Opt Moist	0-6	6-12	12-18	18-24	RWD	Truck Right	Truck Left
615+75	6m R	112.8 (1)	5.44	na	4	11	46	na	0.75	0.50	0.31
616+75	3m R	98.3 (2)	3.79	na	2	20	na	na	0.42	0.41	0.92
619+00	3m R	na	na	na	10	29	11	6	1.19	1.09	2.34
620+45	7m R	98.4 (2)	4.9	71.0	19	25	na	na	1.05	0.92	0.94

(1) Proctor results = 143.8 pcf max dry density @ 6.9% optimum moisture
(2) Based on 120.0 pcf max dry density. Optimum moisture content not provided.
(3) Deflections from axle sensors only average over 5 feet around test location.

Table 2.4.2: Comparative Field Test Data for STH 57 - Sheboygan County, September 28, 2001

Test Location		Nuclear Tests			In-Place CBR				Average Deflection, inch (3)		
Station	Offset	% Rel Comp	% Moist Content	% Opt Moist	0-6	6-12	12-18	18-24	RWD	Truck Right	Truck Left
673+70	2m L	na	na	na	19	6	6	10	2.39	1.07	0.51
695+00	2m L	97.0 (1)	7.6	na	na	na	na	na	1.42	0.65	0.83
696+00	2m L	96.9 (1)	6.0	na	8	13	16	19	1.81	1.41	1.33
706+00	1m R	99.6 (1)	4.6	na	na	na	na	na	0.08	0.12	0.26
715+00	2m R	98.4 (1)	7.2	na	3	na	na	na	**3.22**	**1.87**	**1.15**

(1) Based on 146.0 pcf max dry density. Optimum moisture content not provided.
(3) Deflections from axle sensors only average over 5 feet around test location. Bold values indicate locations “failed” by WisDOT observers.

Table 2.5.1: Comparative Deflection Data for Locations With Low CBR

CBR Criteria	Site	Date	CBR				Deflection, inch		
			0-6	6-12	12-18	18-24	RWD	RAxle	LAxle
Low 0-6 Only	CTH SS	5/31	4	11				4.03	3.49
	CTH SS	6/28	3	14	20	24		1.69	2.89
	CTH SS	6/28	3	14	20	24		2.54	1.16
	CTH SS	6/28	6	19	49			1.19	0.87
	CTH SS	6/28	6	20	14	14		1.74	1.88
	USH 41	9/27	1	7	19	14	2.97	2.53	1.75
	USH41	9/27	4	14	8	29	1.38	1.39	2.00
	STH 57	9/4	2	20			0.42	0.41	0.92
	STH 57	9/4	4	11	46		0.75	0.50	0.31
Low 6-12	none								
Low 12-18 Only	CTH SS	6/28	10	7	6	14		1.06	0.33
	STH 57	7/11	39	17	6	7	0.02	0.15	0.01
Low 18-24 Only	CTH SS	5/31	10	10	7	3		1.78	3.40
	CTH SS	7/11	7	17	13	4		0.90	1.51
	CTH SS	7/11	7	17	13	4		0.62	0.41
	STH 57	7/11	20	17	11	6	0.40	0.70	0.40
	STH 57	9/4	10	29	11	6	1.19	1.09	2.34
Low 0-12 Only	STH 57	9/28	3				3.22	1.87	1.15
Low 12-24 Only	STH 57	7/11	16	7	4	6	-0.10	-0.31	0.04
	STH 57	7/11	61	17	6	6	0.30	0.97	0.36
	STH 57	7/11	61	17	6	6	0.11	0.65	0.58
	STH 57	7/11	14	11	6	6	0.38	0.73	-0.12
Low 0-24 All	CTH SS	5/31	3	4	2	3		3.39	1.19
	STH 57	9/28	3				3.22	1.87	1.15

Table 2.5.2: Comparative Deflection Data for Locations Identified as "Failed"

Test Location			Average Deflection, inch			Maximum Deflection, inch		
Site	Date	Stations	RWD	Truck		RWD	Truck	
				Right	Left		Right	Left
CTH SS	5/31/01	20+430 - 20+450 N	na	2.07	1.97	na	4.63	2.87
CTH SS	5/31/01	20+430 - 20+450 S	na	1.32	1.97	na	2.50	5.09
CTH SS	5/31/01	20+560 - 20+580 N	na	2.93	2.63	na	5.64	4.30
CTH SS	6/28/01	36+057 - 36+043 N	na	1.62	1.68	na	2.29	2.22
CTH SS	6/28/01	36+050 - 36+054 S	na	2.15	1.62	na	3.38	2.92
CTH SS	6/28/01	9+71 - 9+82	na	2.27	1.29	na	3.31	2.64
CTH SS	7/11/01	36+035 - 36+045 S	na	.38	.23	na	0.85	0.48
CTH SS	7/11/01	36+055 - 36+065 S	na	.62	.41	na	0.92	0.62
CTH SS	7/11/01	36+115 - 36+130 N	na	1.32	1.54	na	2.17	3.38
CTH SS	7/11/01	36+115 - 36+130 S	na	1.26	1.61	na	2.12	2.93
CTH SS	7/11/01	35+840 - 35+860 S	na	.58	.78	na	1.16	1.60
CTH SS	7/11/01	35+840 - 35+860 N	na	1.53	1.51	na	2.63	3.03
CTH SS	7/11/01	36+815 - 36+825 S	na	1.18	1.27	na	1.70	1.90
USH 41	8/31/01	16+160 - 16+180	na	1.51	0.56	na	2.40	1.42
USH 41	8/31/01	16+300 - 16+400	na	1.74	1.79	na	4.42	4.30
USH 41	8/31/01	4+250 - 4+280	na	0.03	0.14	na	0.53	0.73
USH 41	8/31/01	18+070 - 18+190	na	1.97	2.30	na	3.80	3.42
USH 41	9/27/01	16+500 - 16+514	1.82	1.34	1.23	2.46	3.14	2.02
USH 41	9/27/01	4+150 - 4+088	1.38	1.30	1.32	2.38	2.65	3.24
STH 57	9/28/01	713+50 - 713+80 E	3.02	1.89	0.86	4.01	2.54	1.50
STH 57	9/28/01	693+50 - 693+90 W	2.34	1.52	0.52	2.88	1.78	1.13
STH 57	9/28/01	693+50 - 693+90 E	2.26	2.31	1.86	2.87	2.92	2.52

Table 2.5.3: Errors Associated With Various Deflection Acceptance Thresholds

Deflection Acceptance Threshold (inch)	Probability of Error, %	
	Type 1 [(1)]	Type 2 [(2)]
1.00	21.1	17.2
1.25	13.0	29.5
1.50	7.7	42.8
1.75	4.8	56.5
2.00	3.1	67.6

[(1)] Type 1 error probability indicates percentage of time passing grade would be rejected

[(2)] Type 2 error probability indicates percentage of time failing grade would be accepted

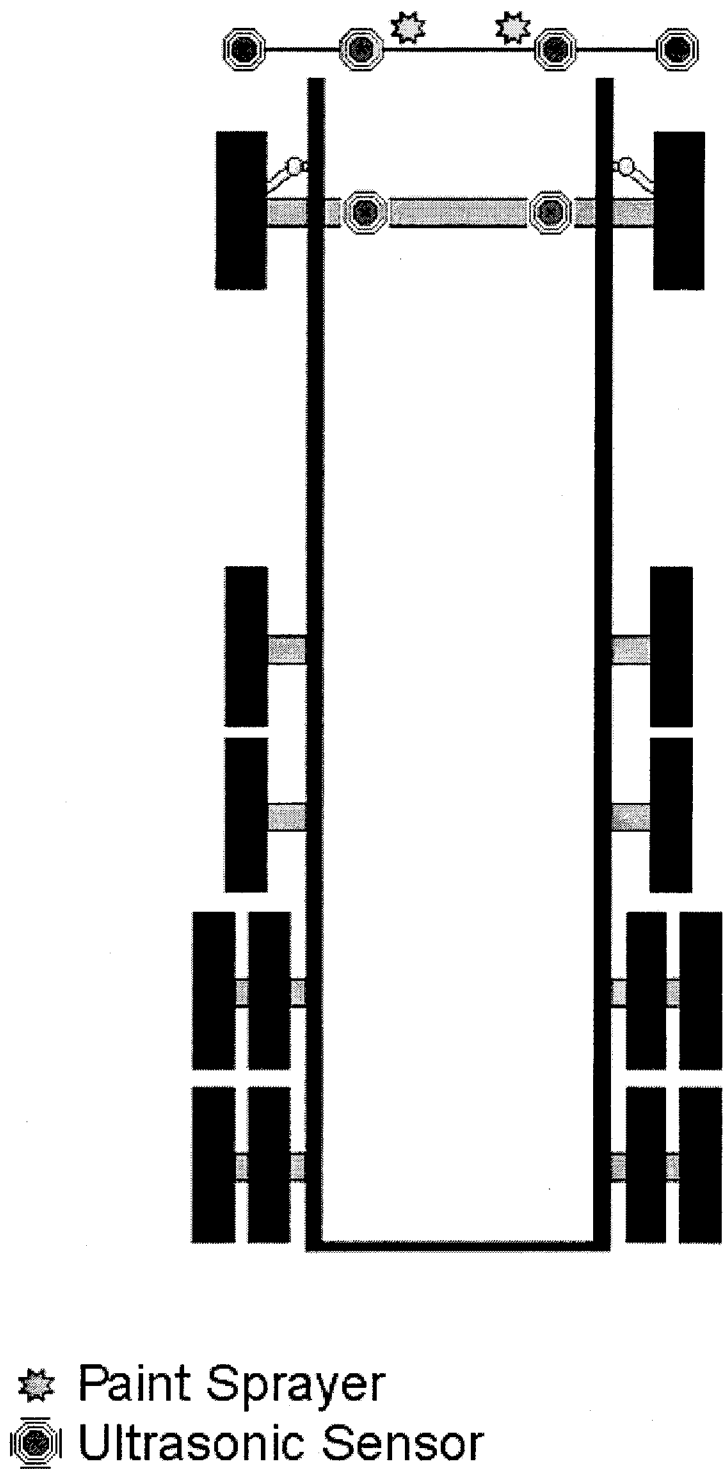


Figure 1.1.1: Schematic of truck configuration Utilized During Pilot Implementations

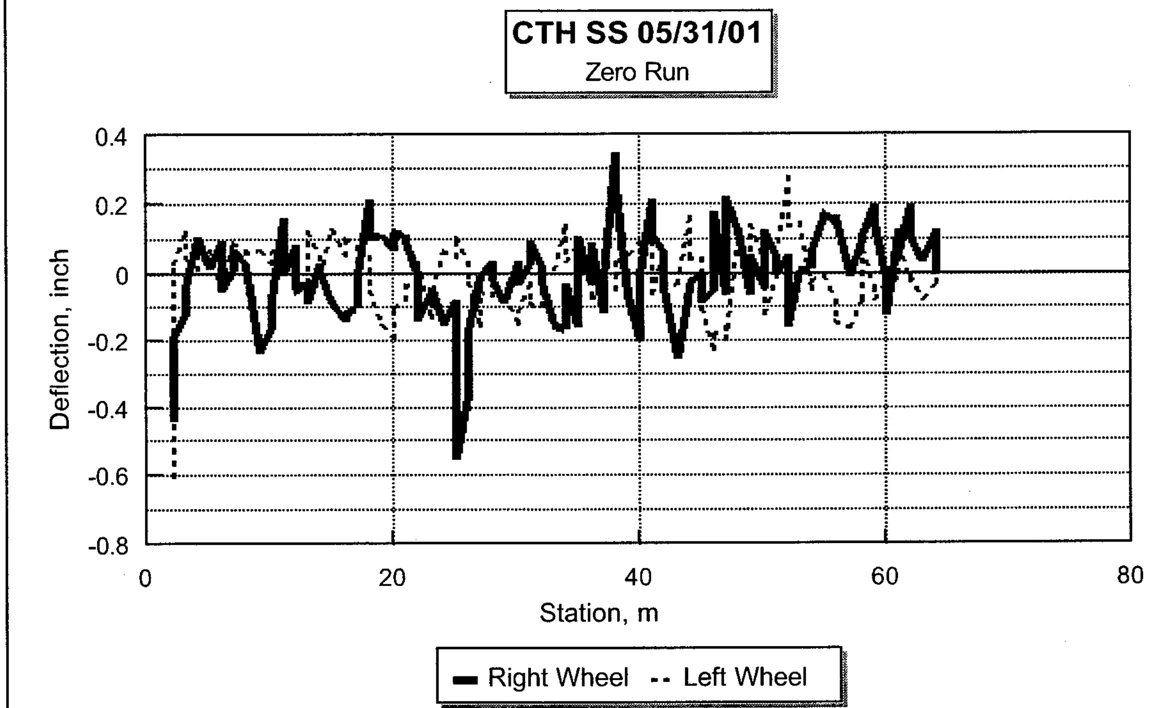


FIgure 2.1.1

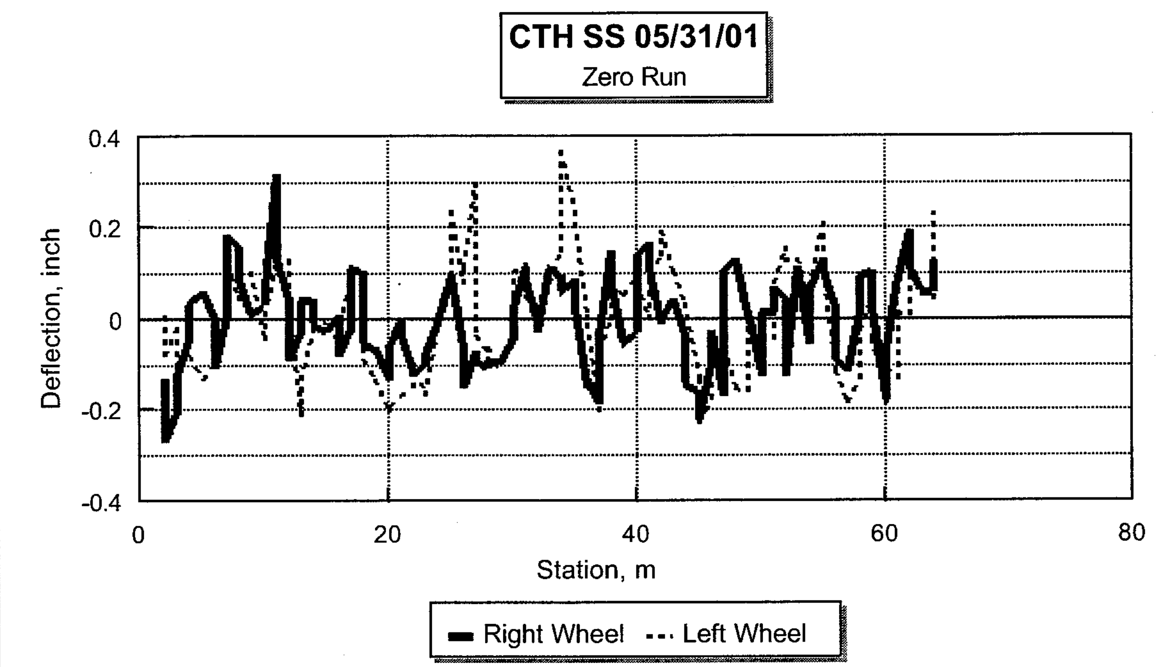


Figure 2.1.2

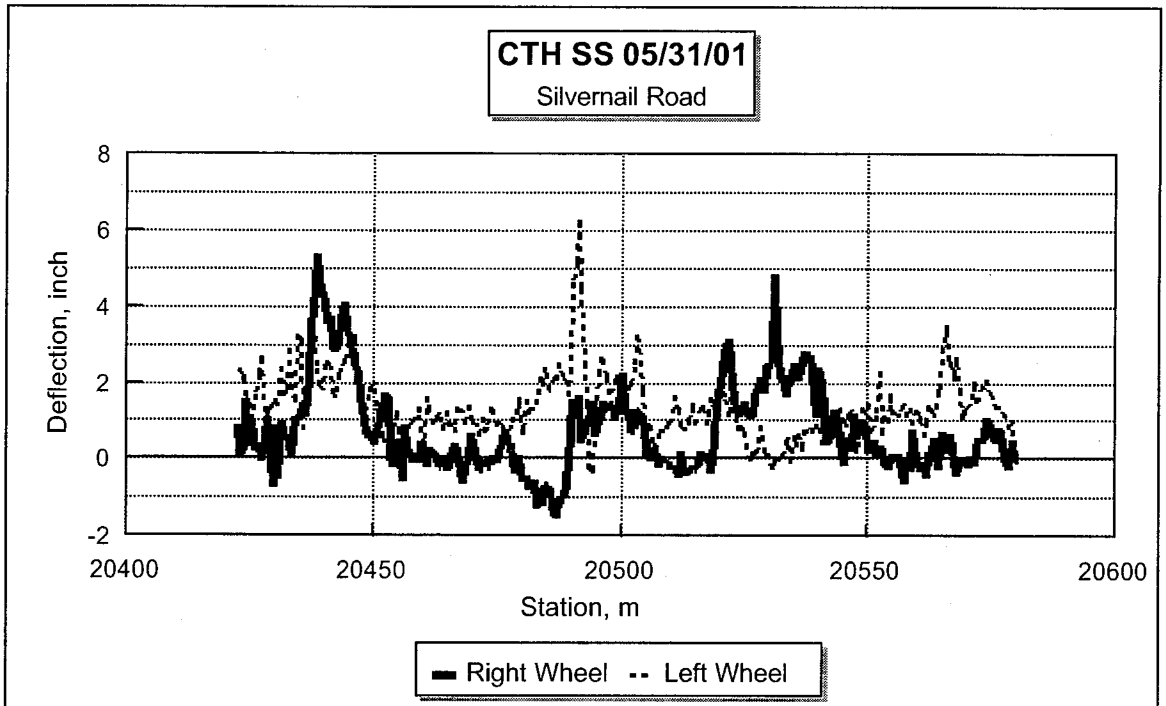
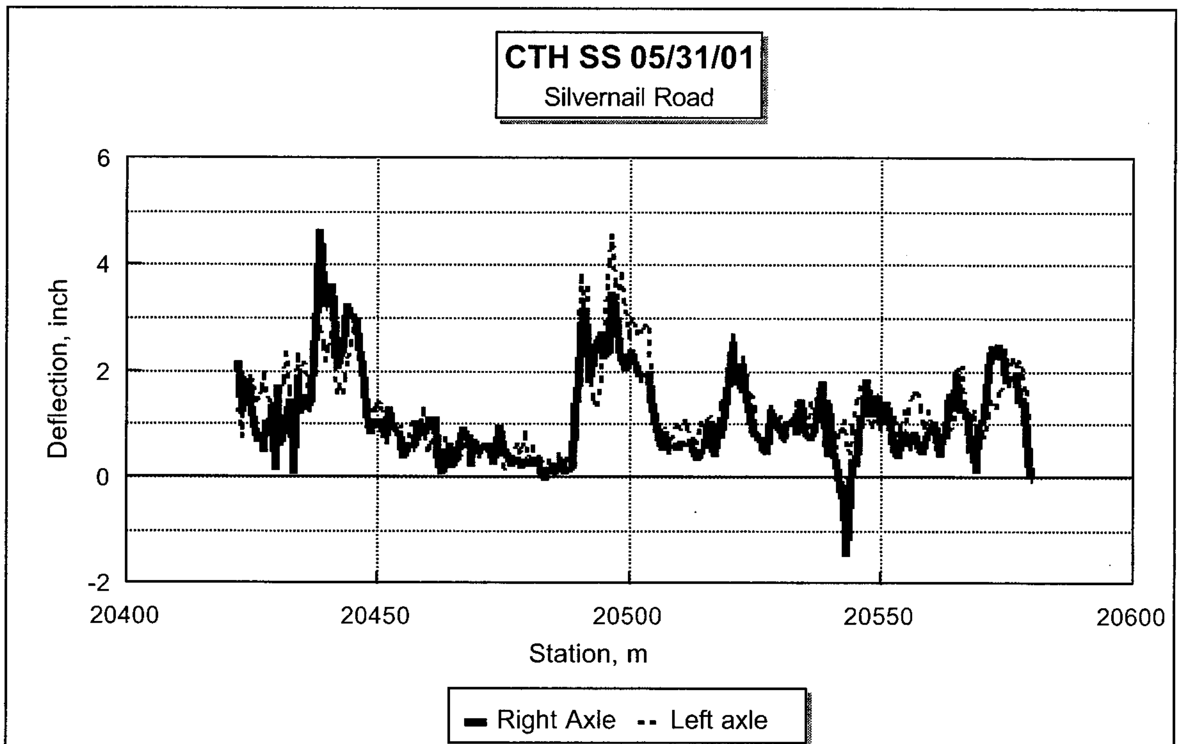


Figure 2.1.3



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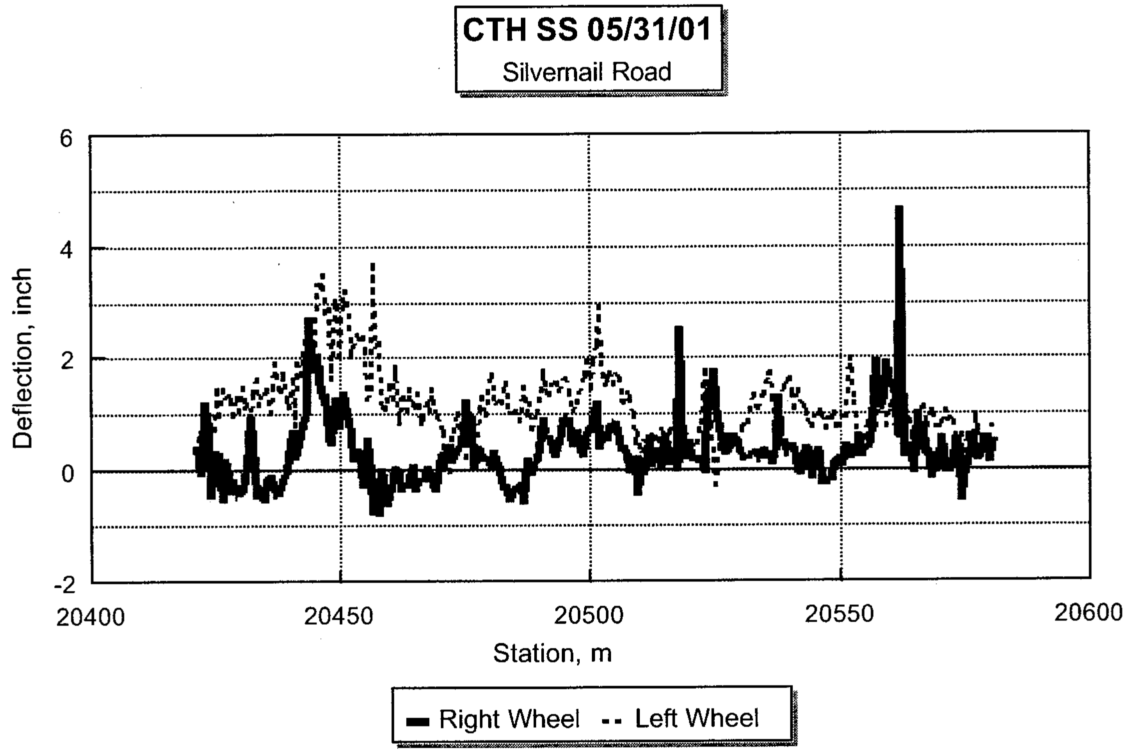
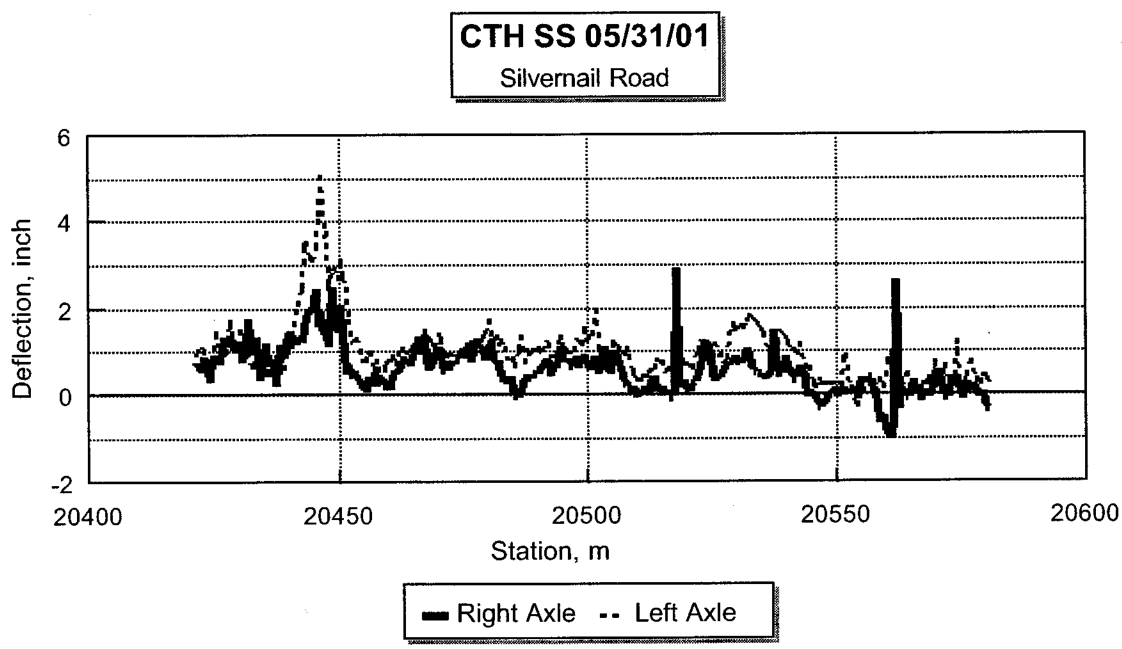


Figure 2.1.5



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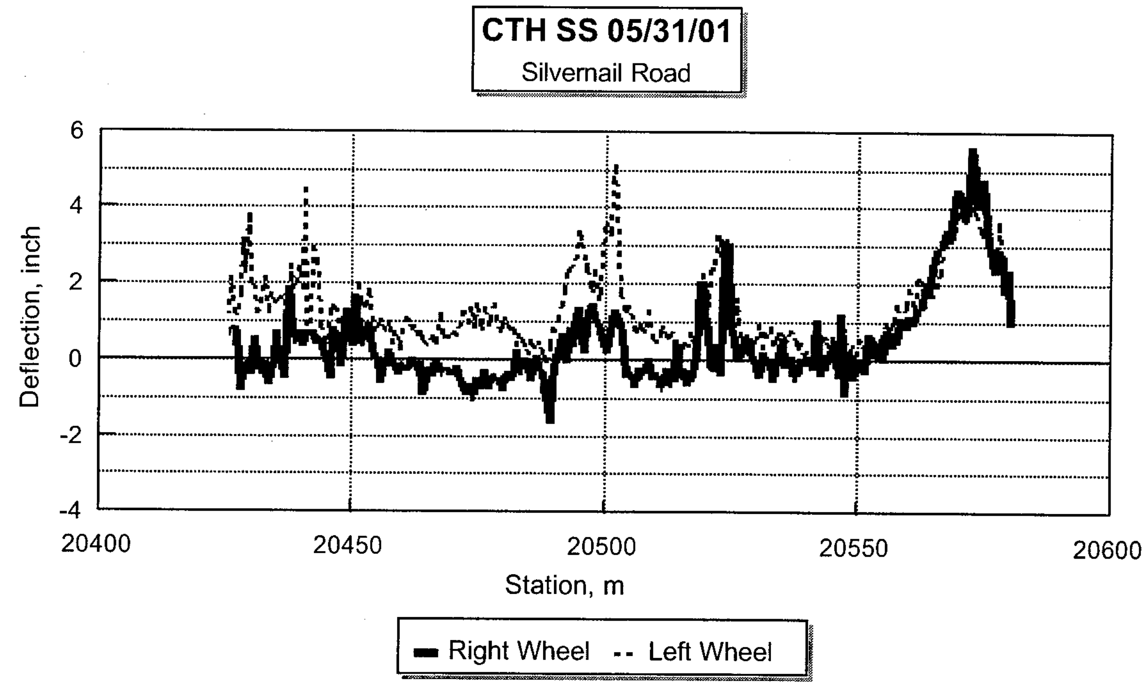

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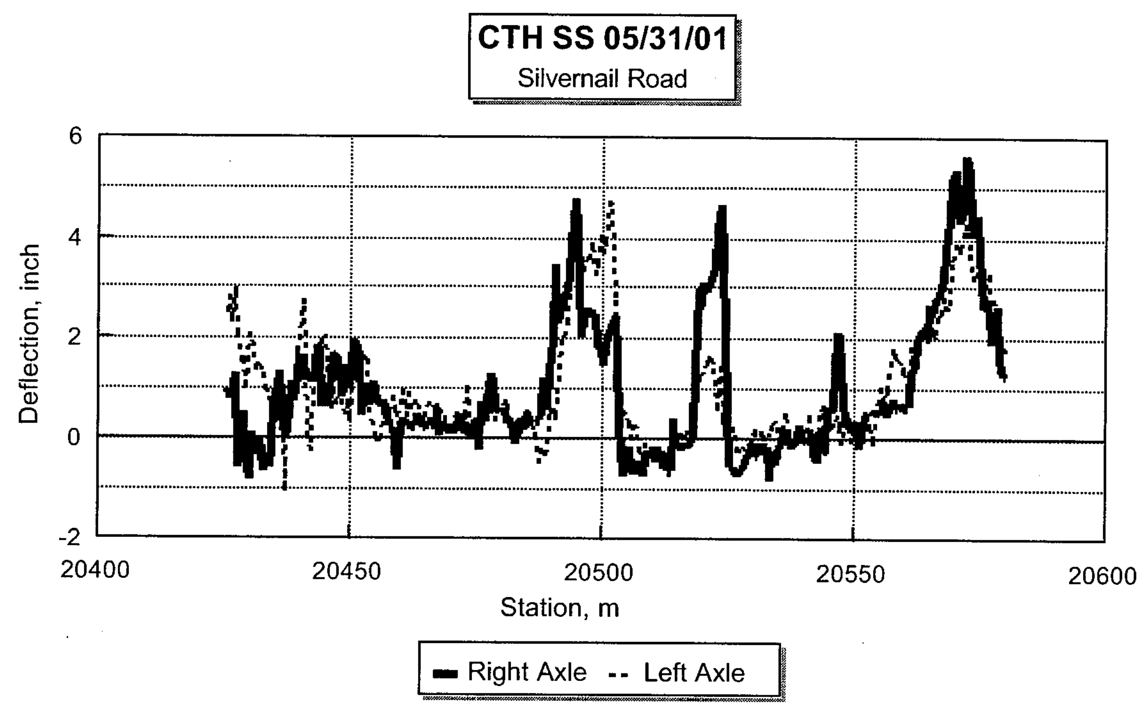

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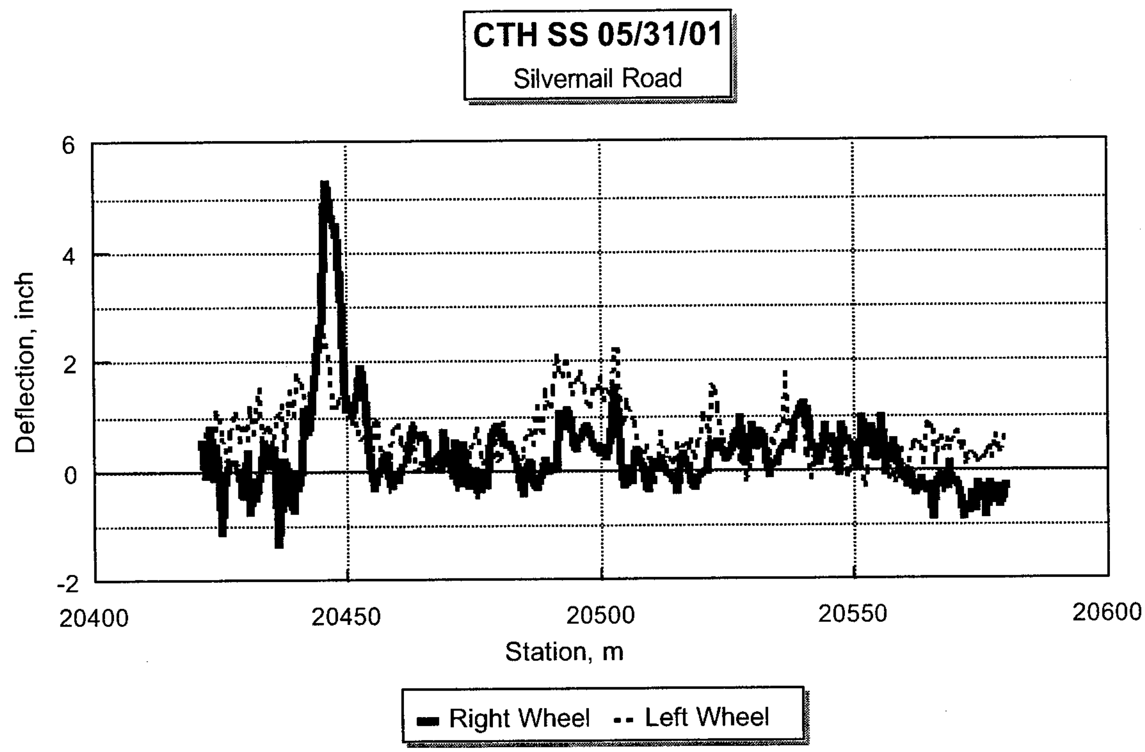

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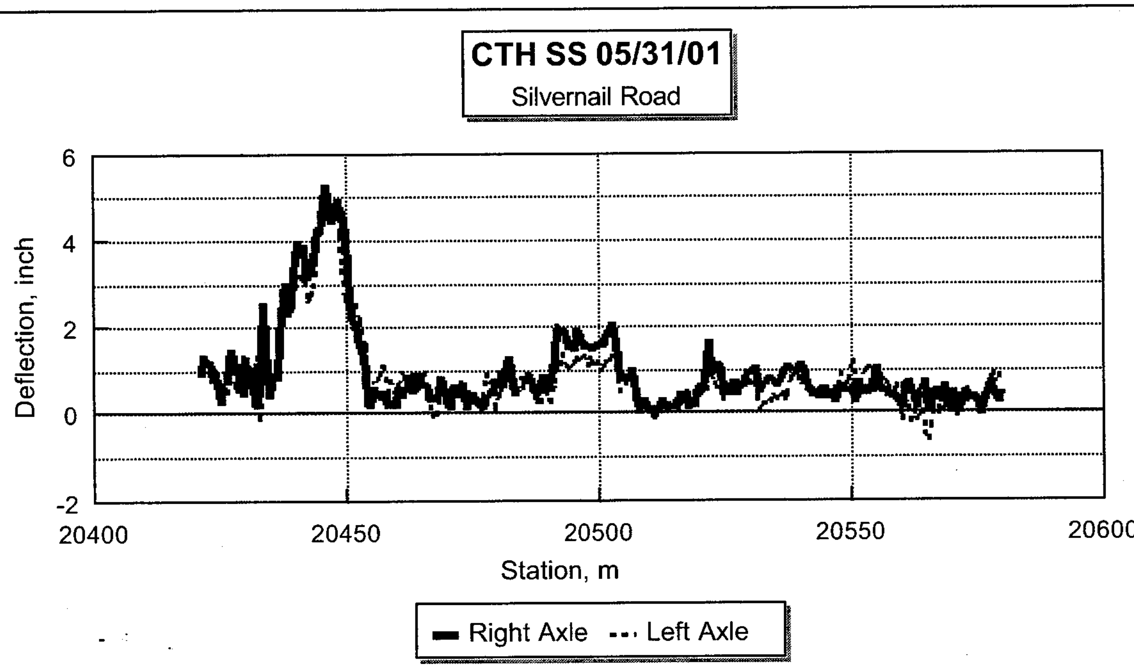

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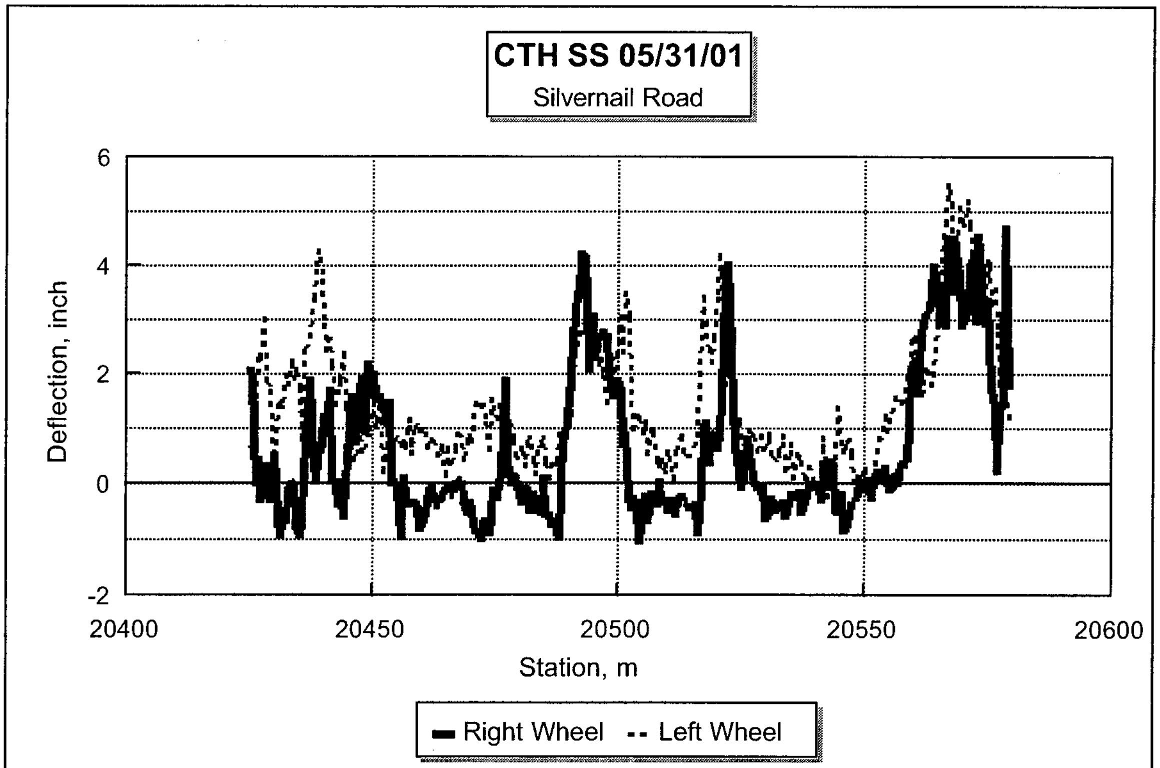

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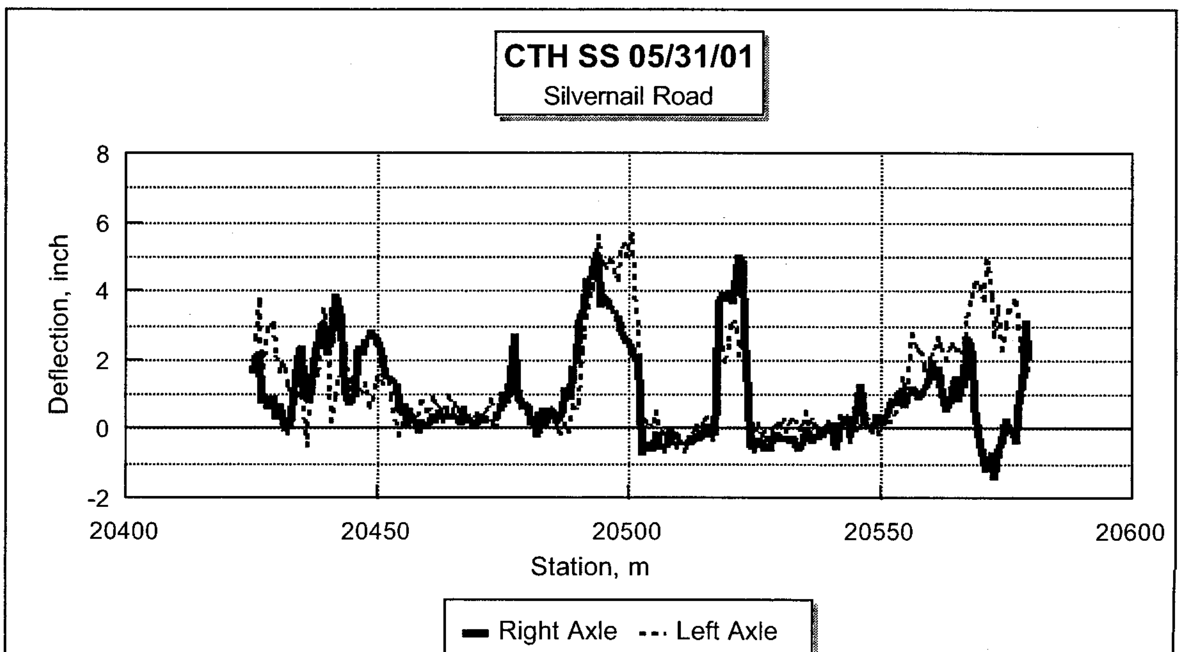
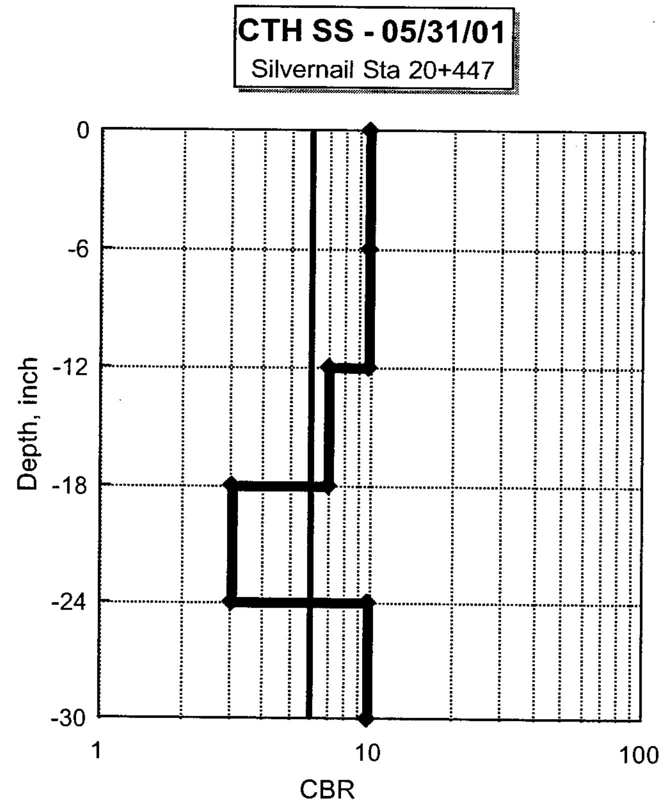


Figure 2.1.12



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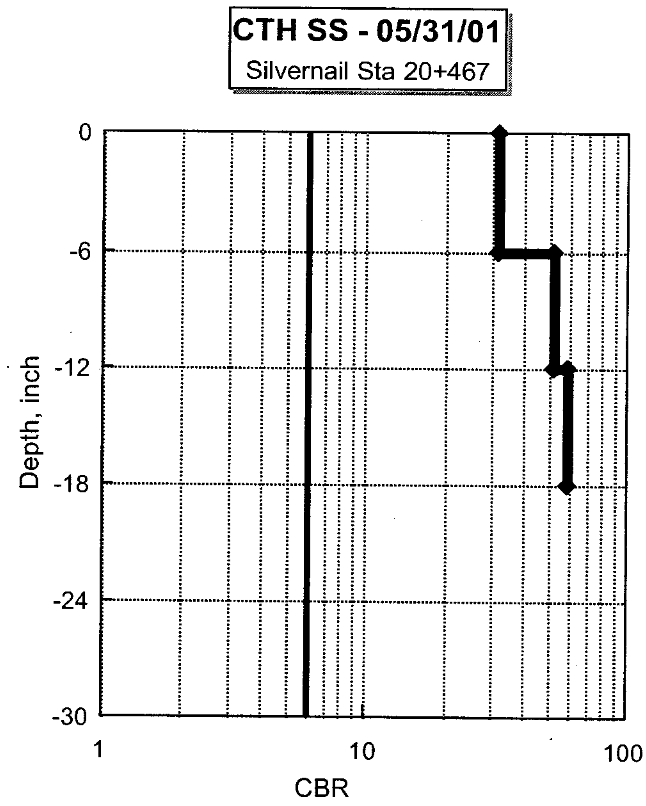

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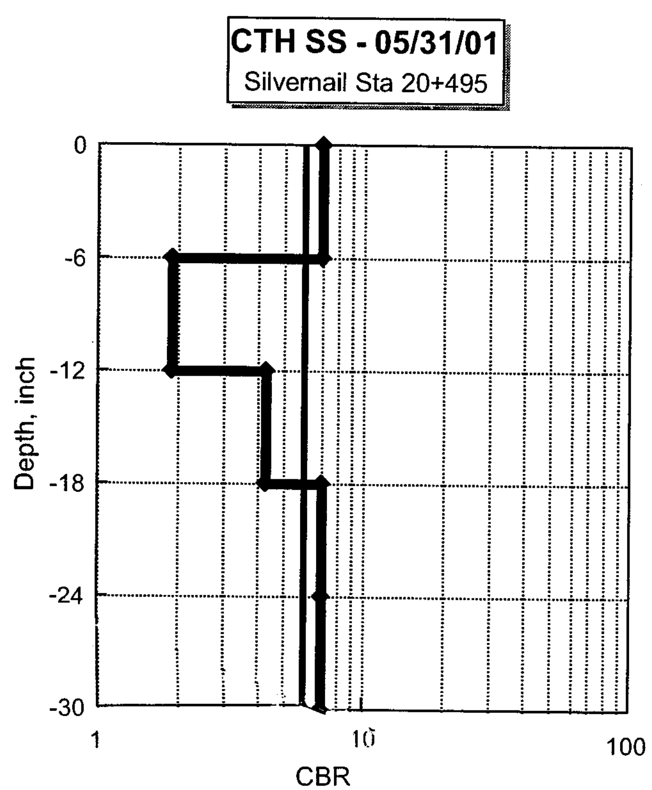

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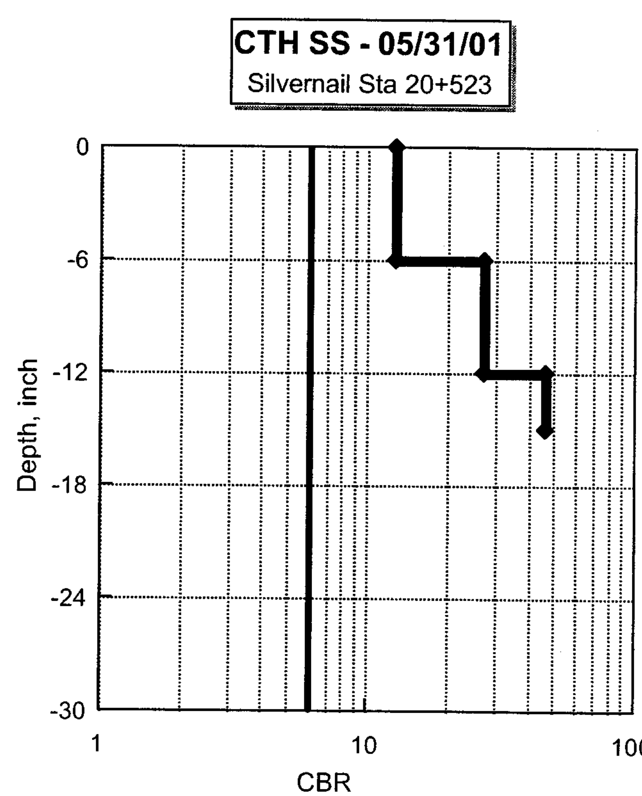

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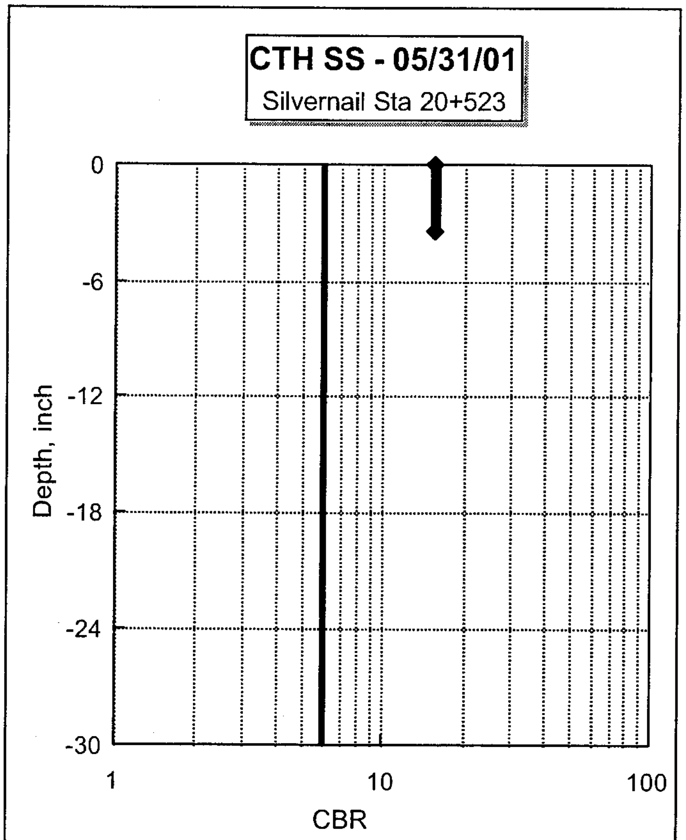

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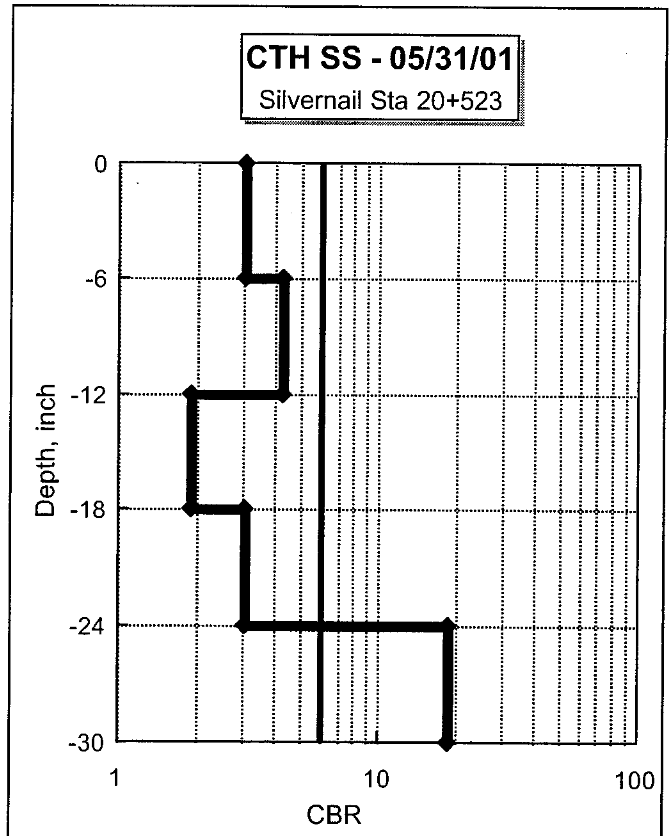

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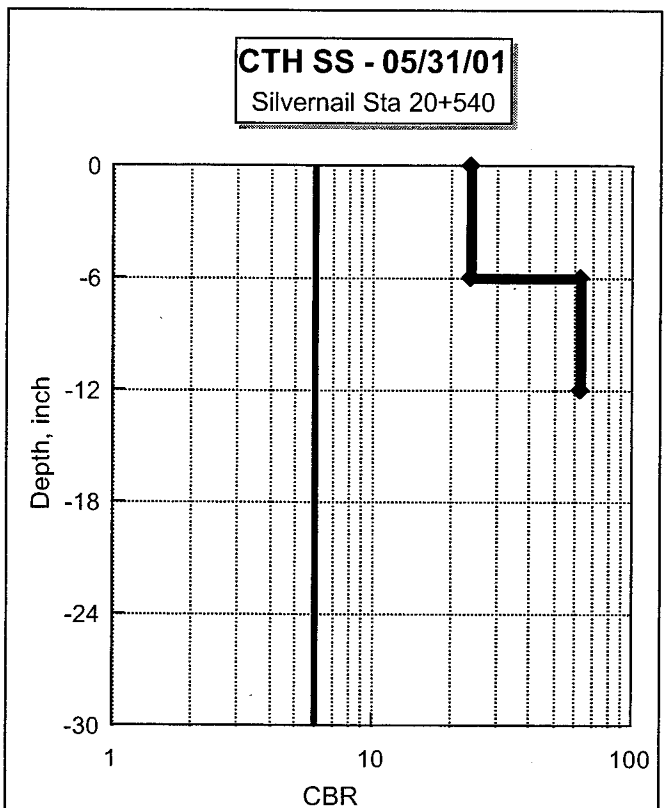

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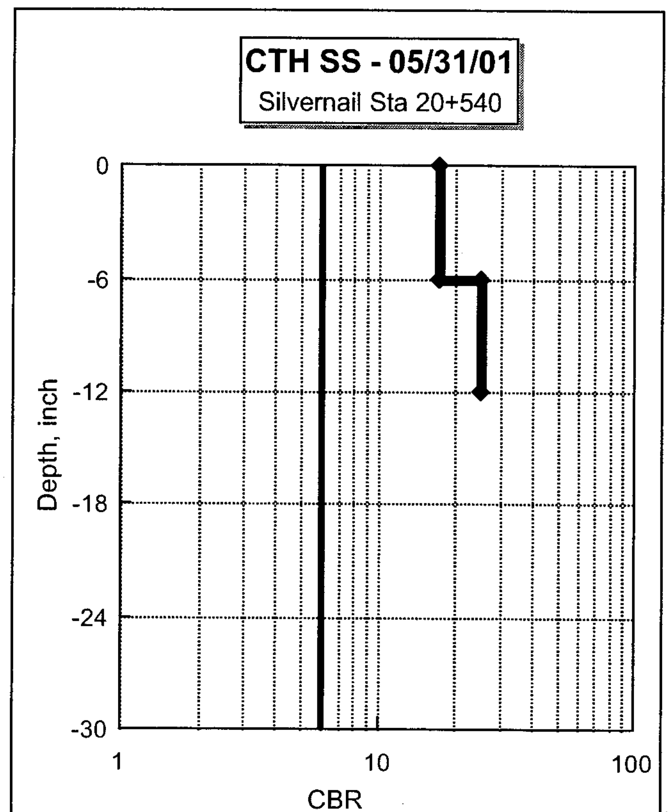

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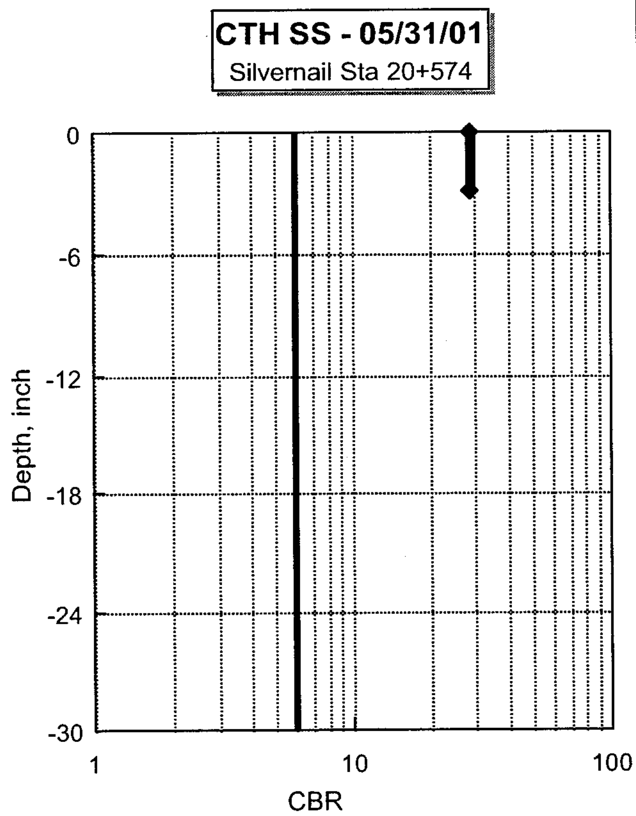

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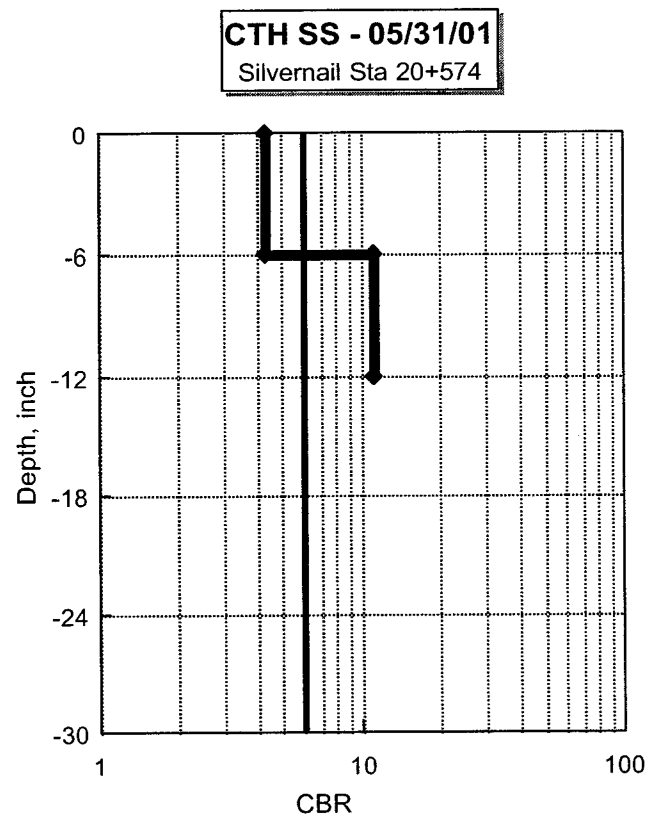

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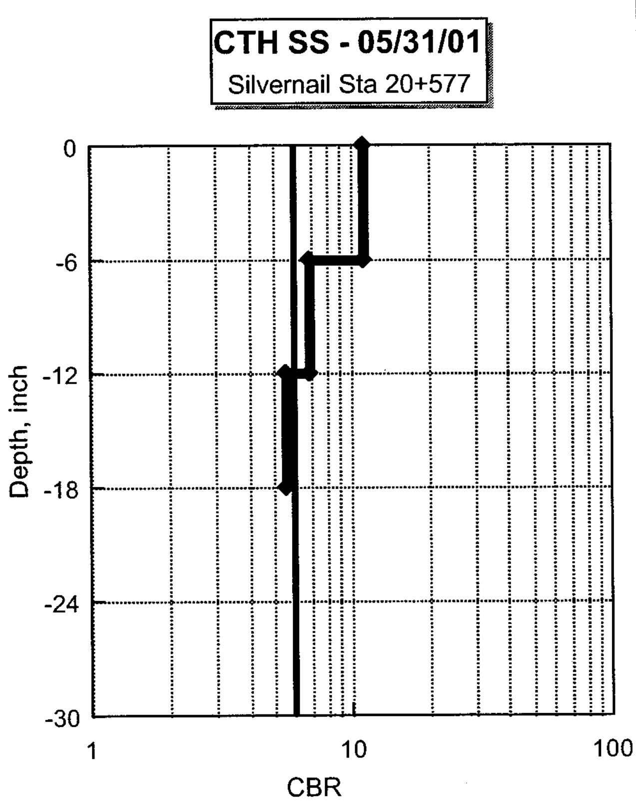

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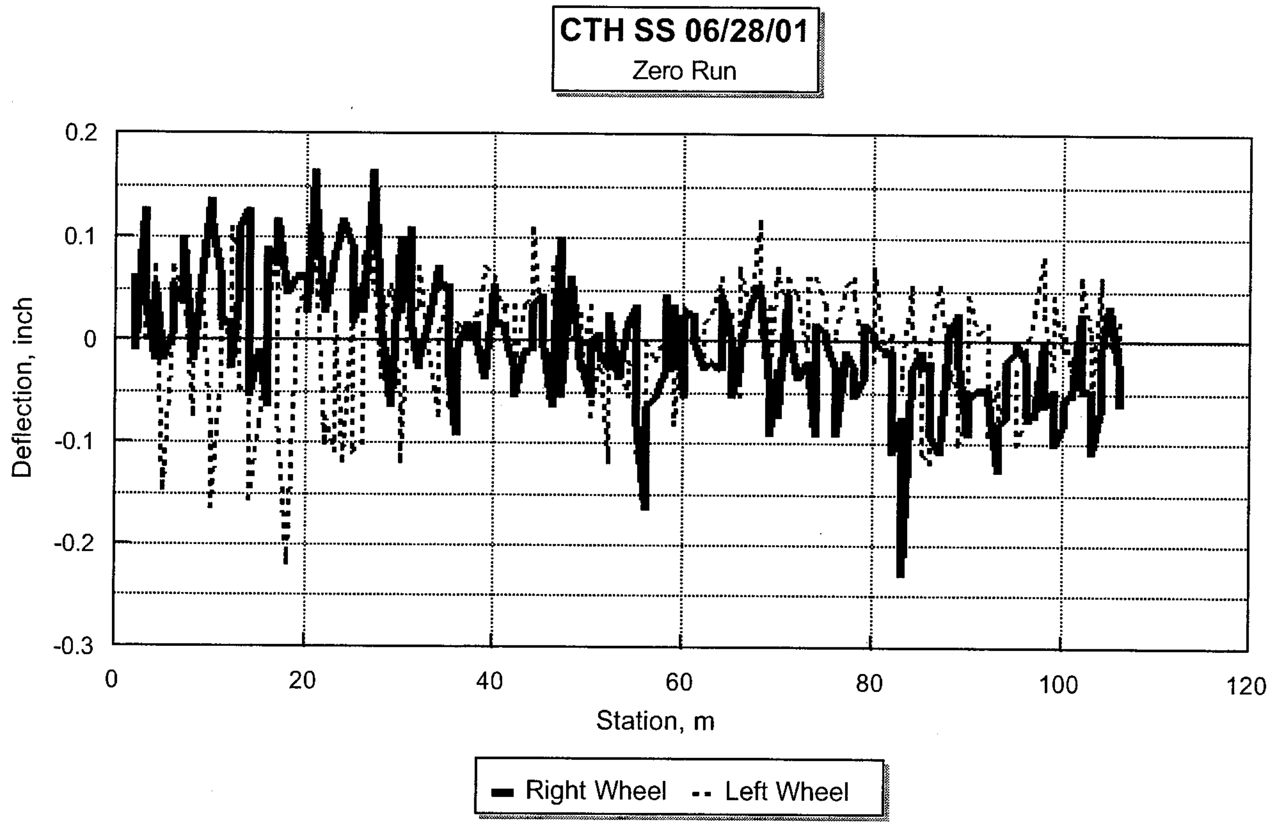

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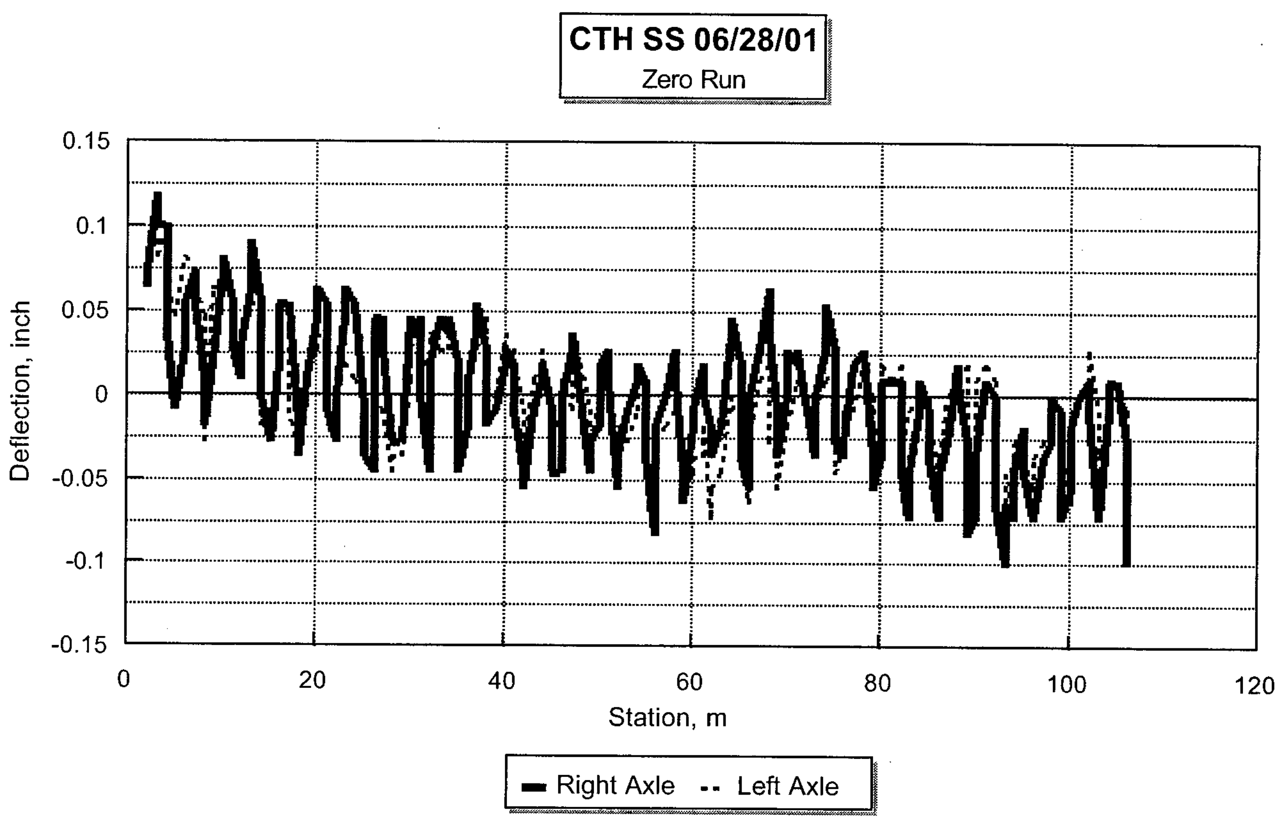

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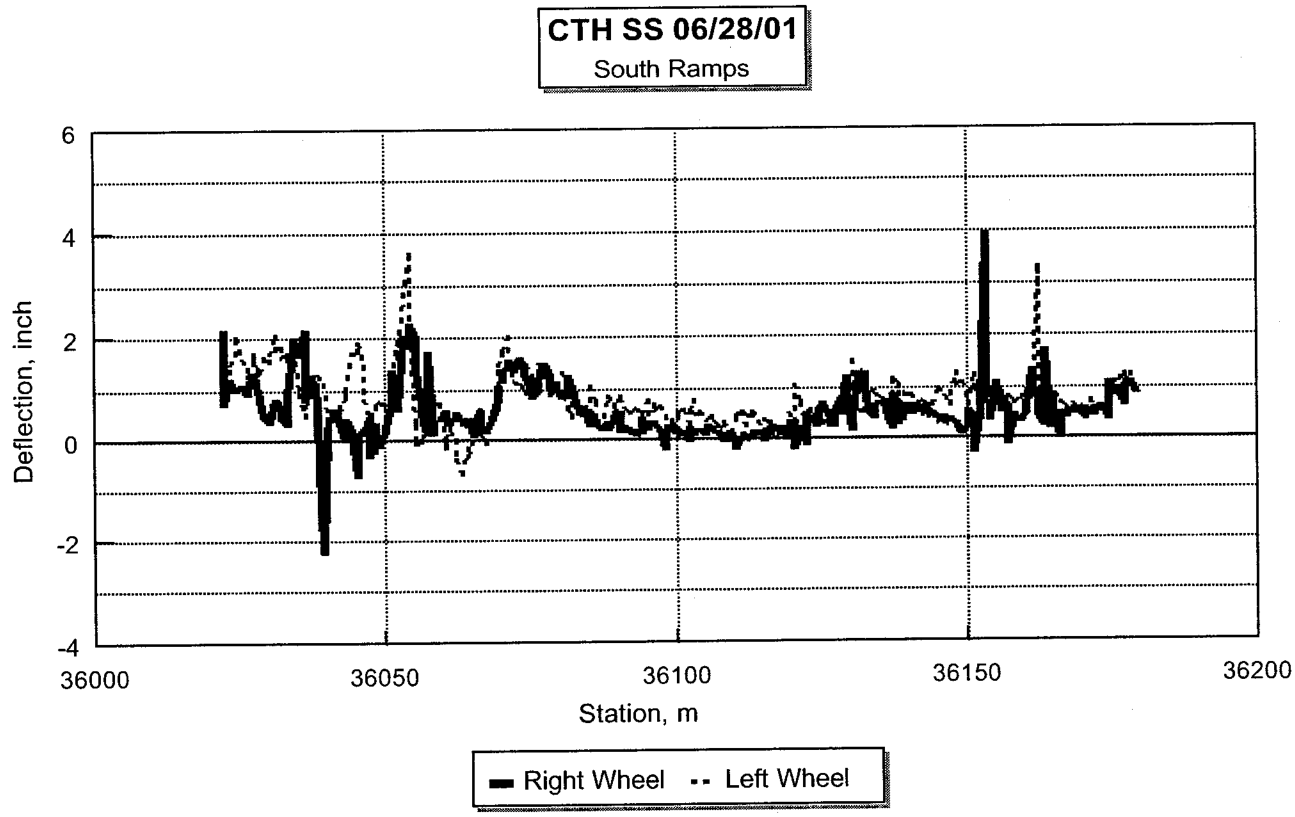

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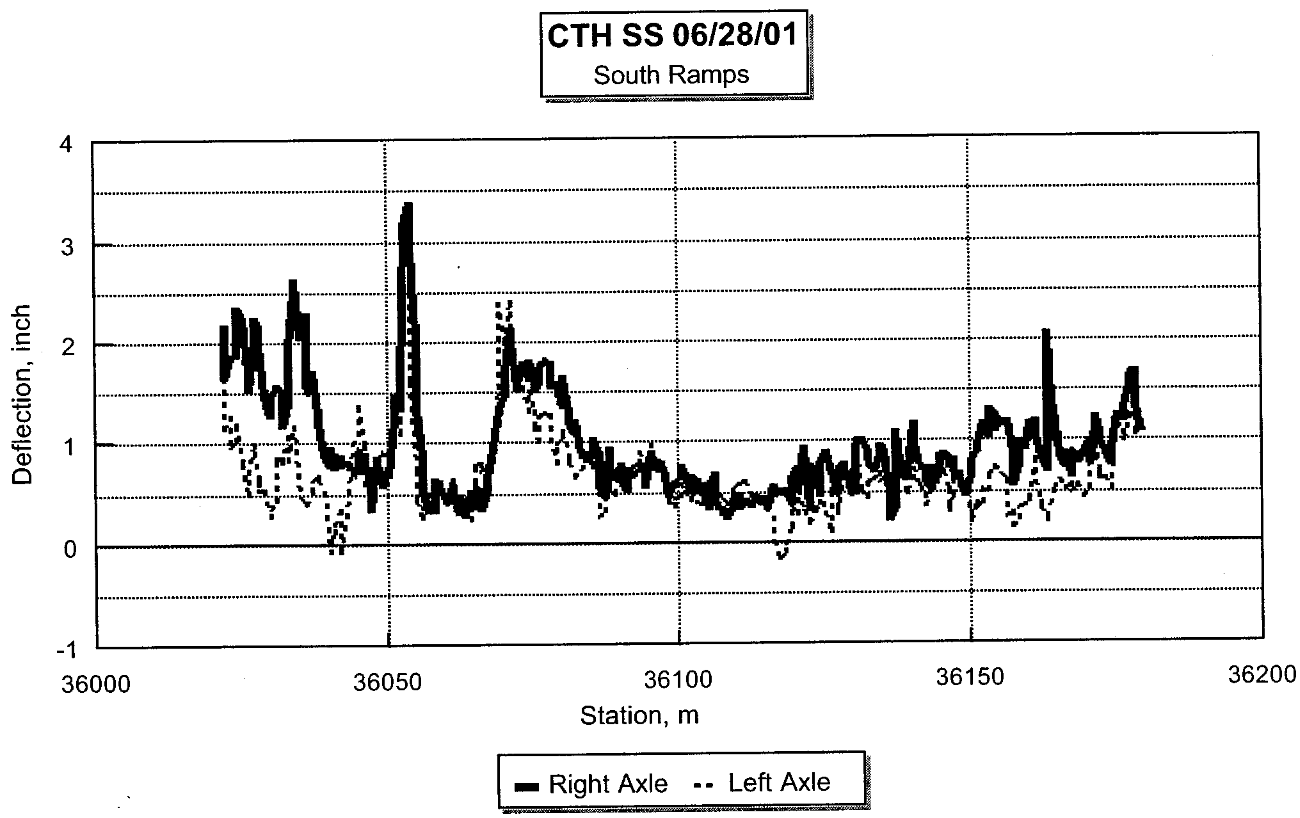

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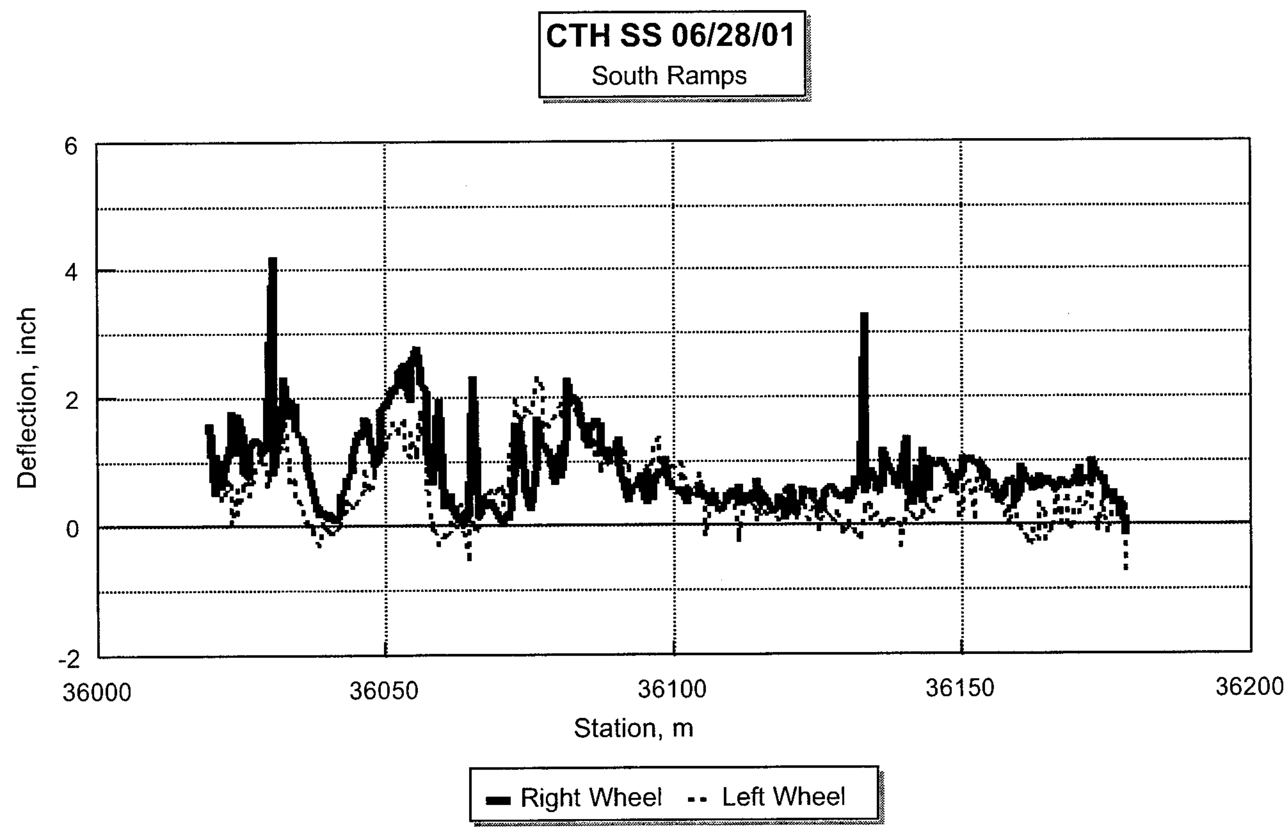

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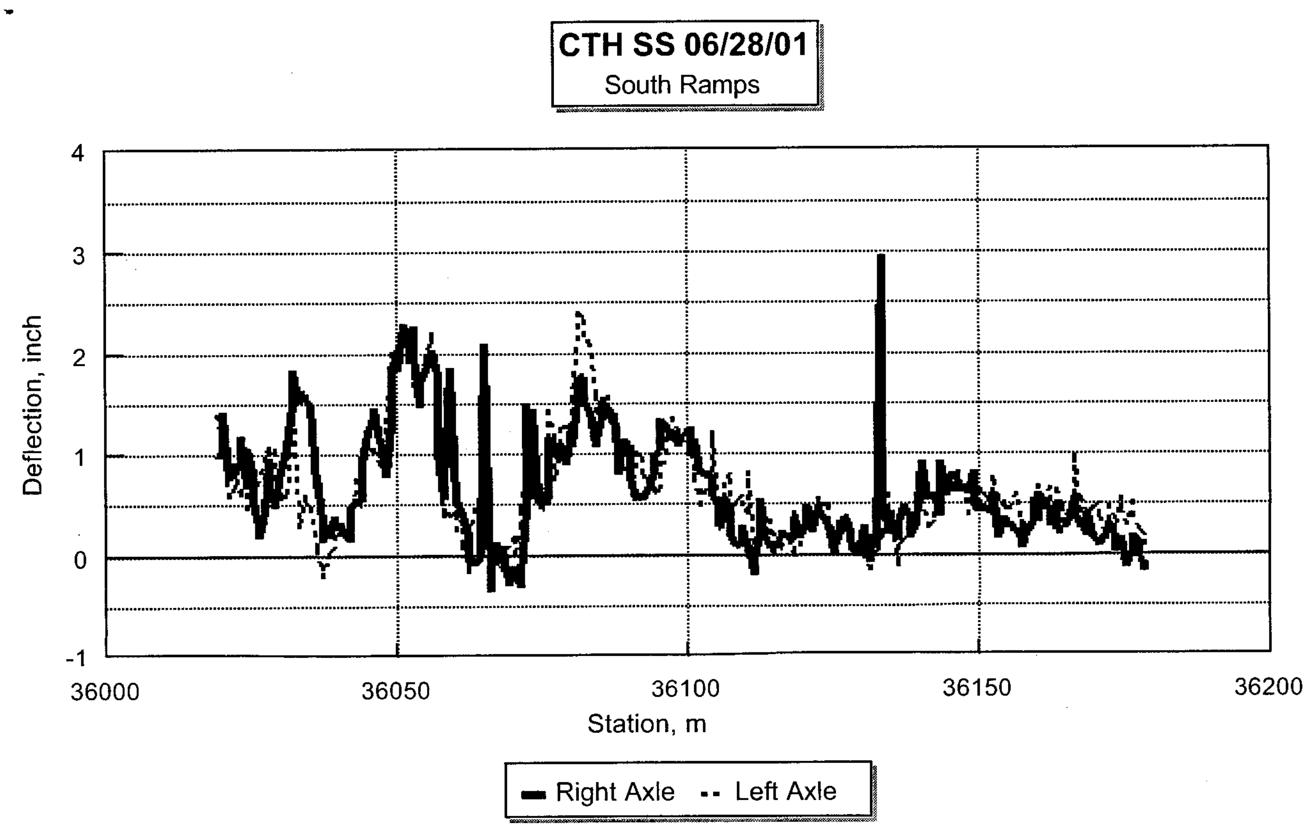

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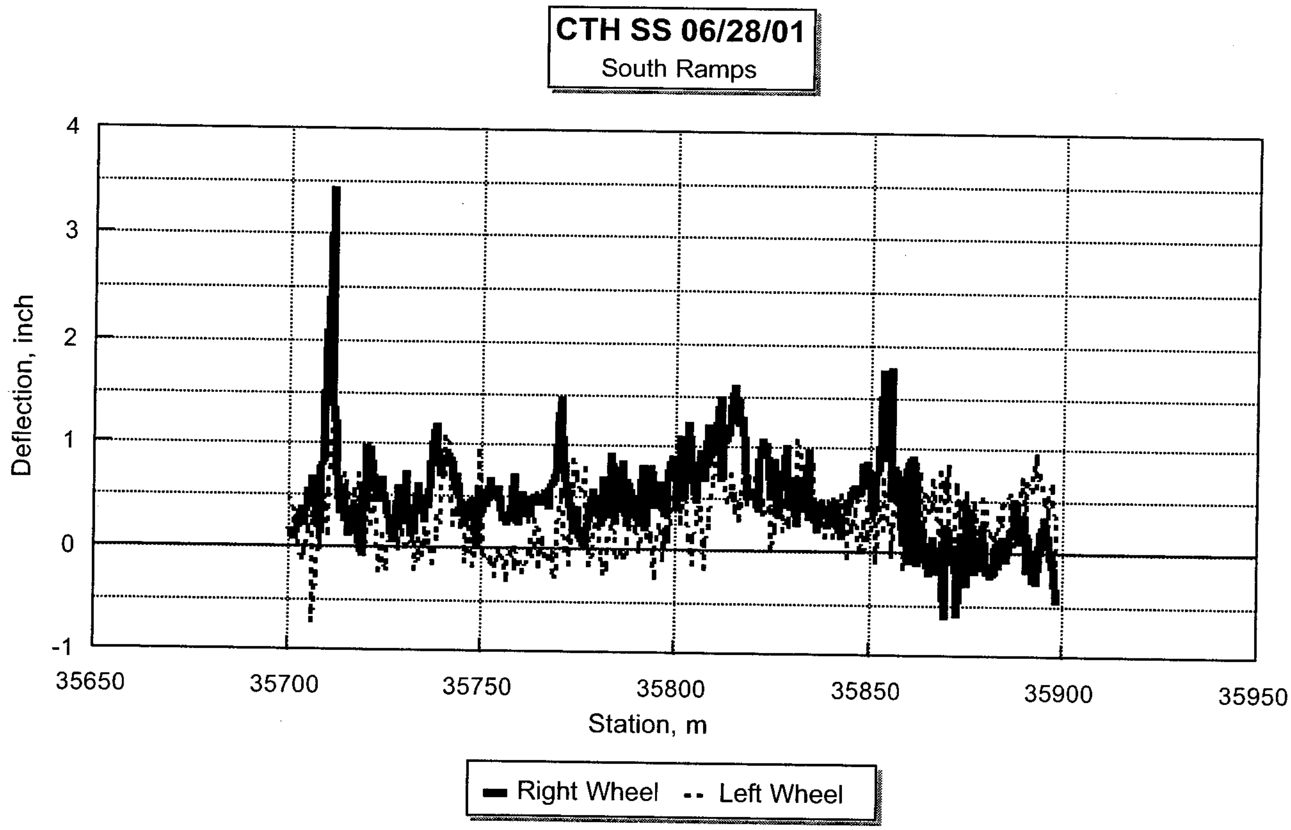

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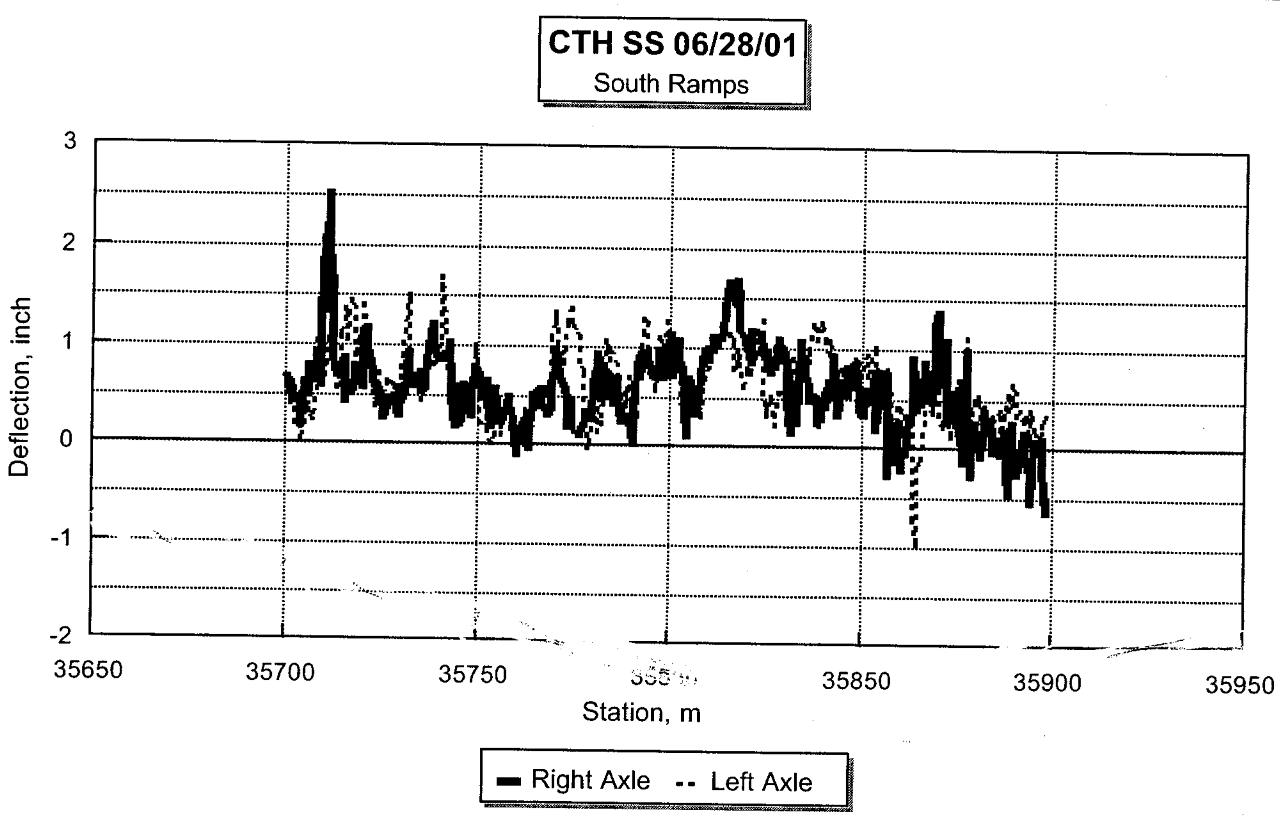

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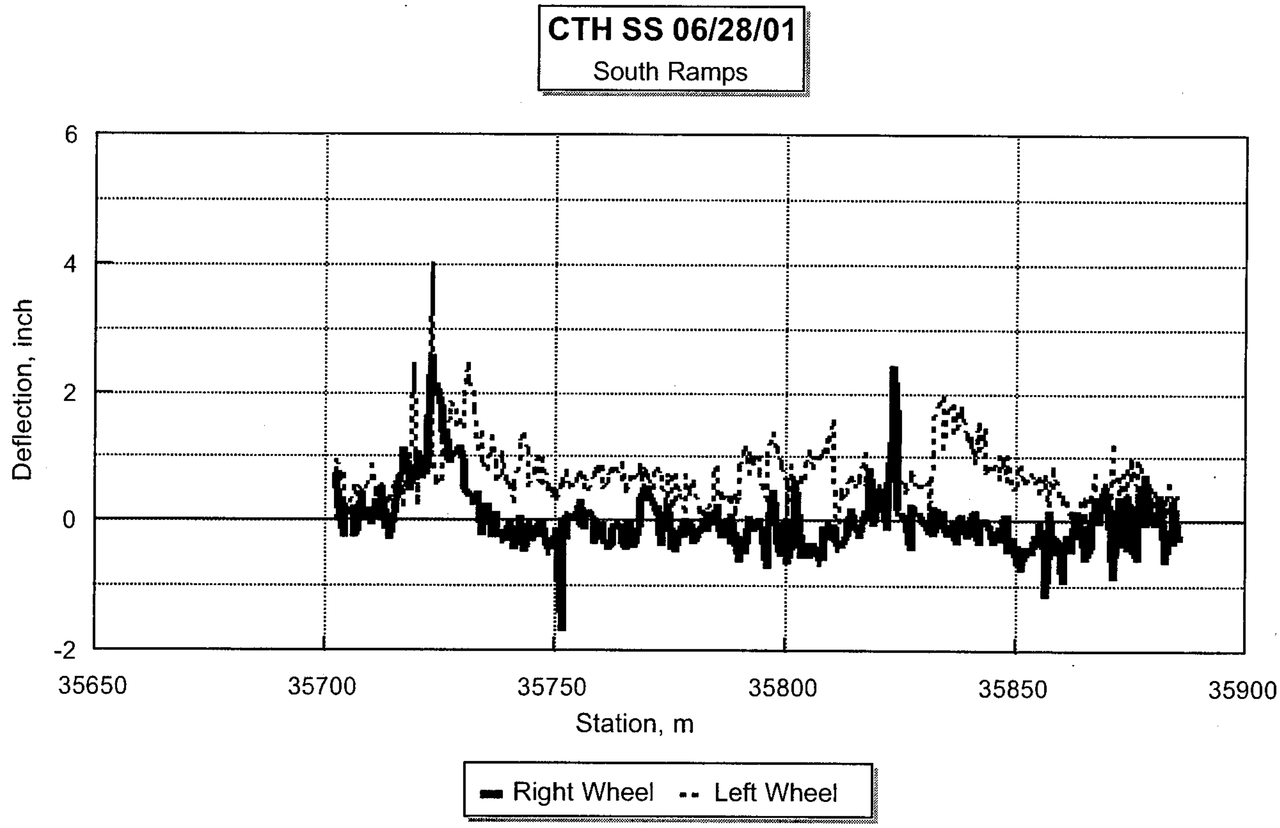

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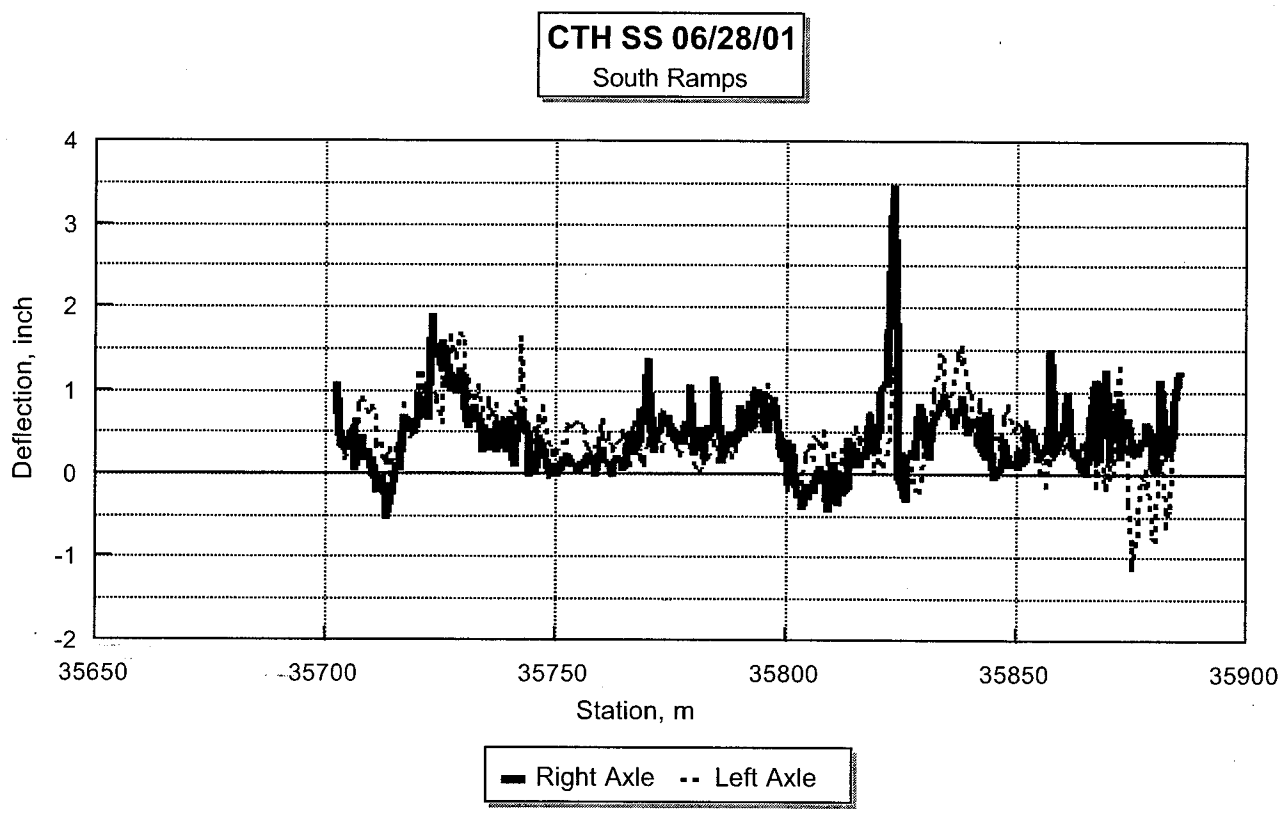

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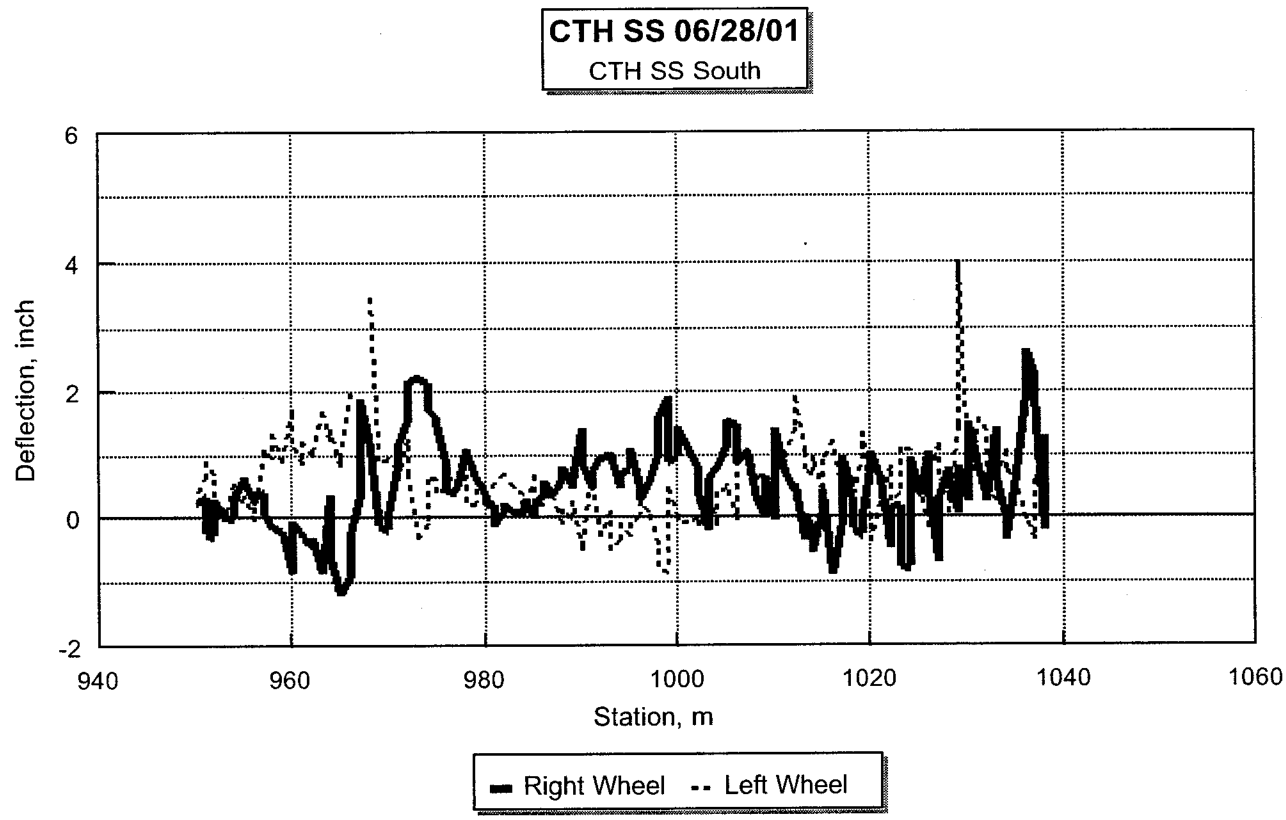

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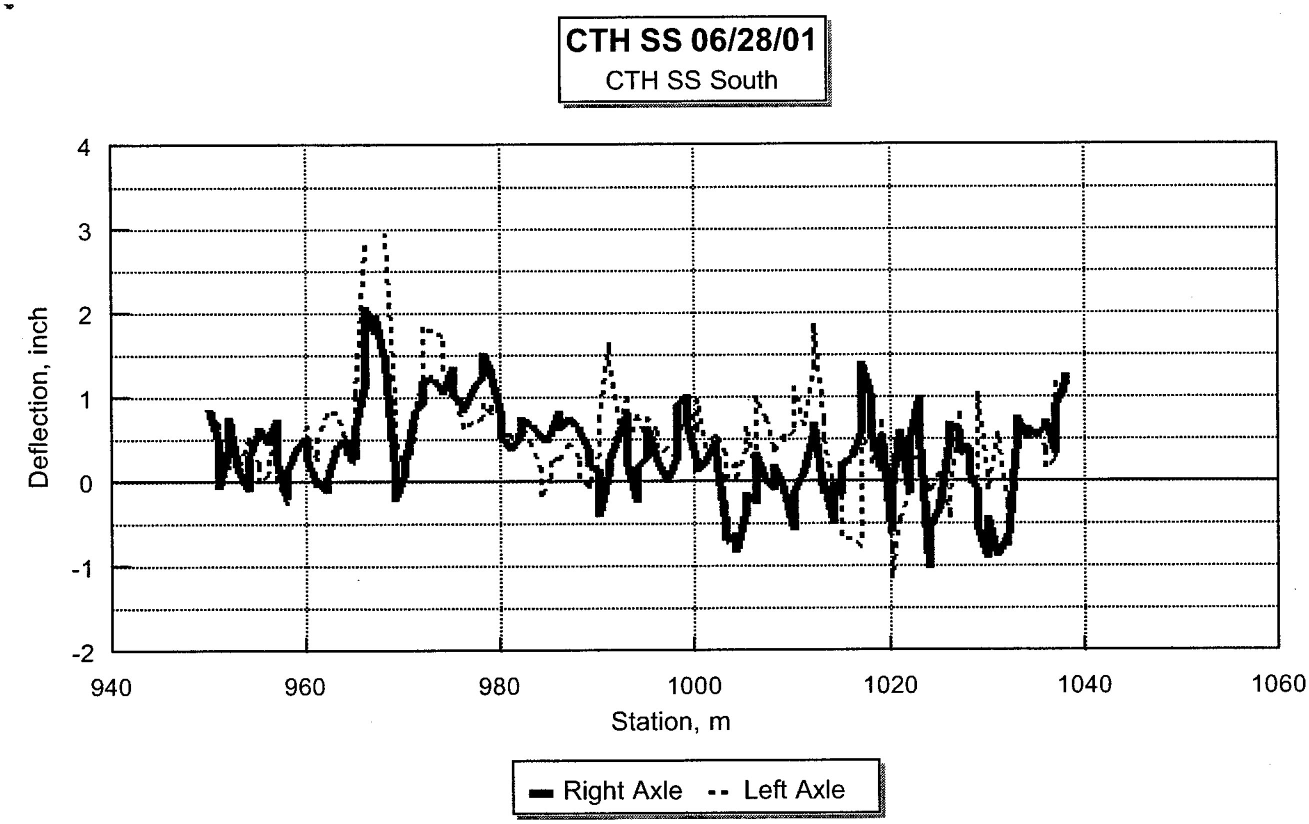

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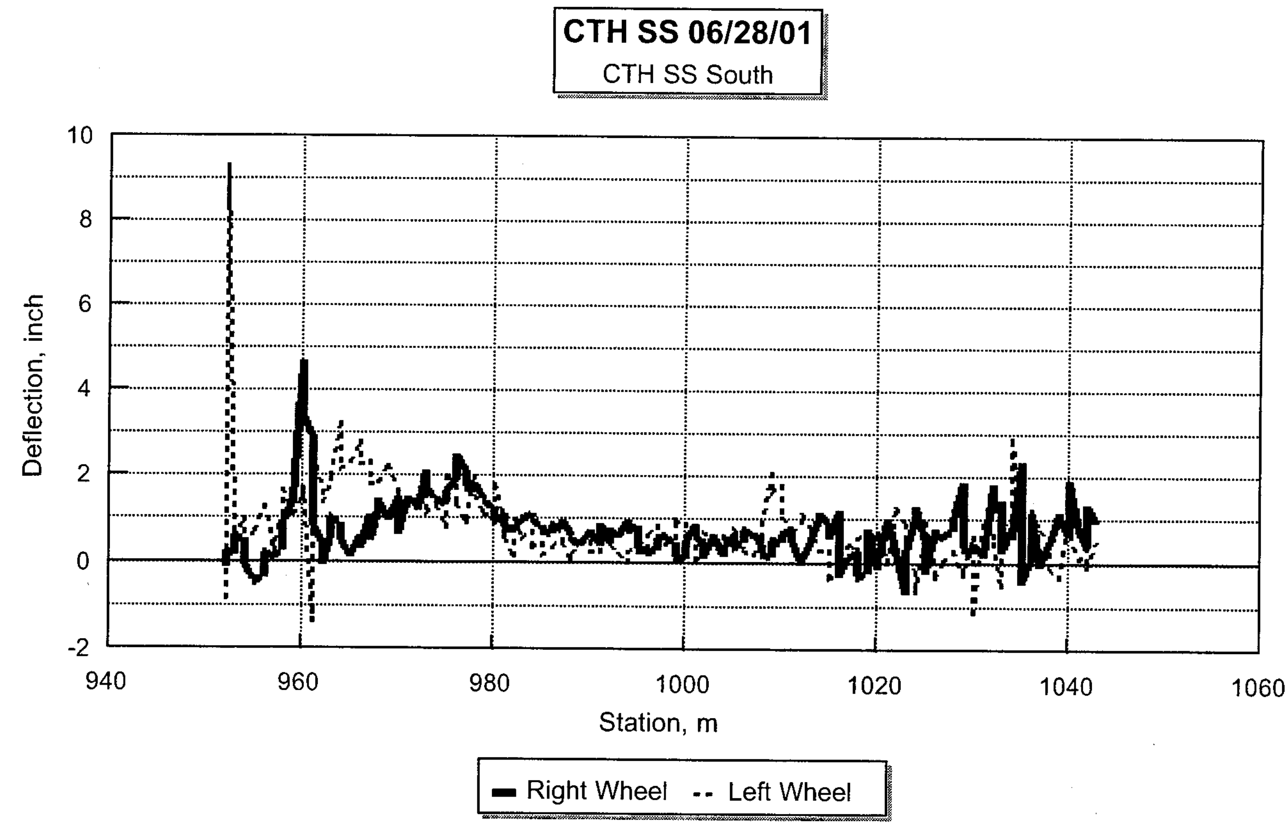

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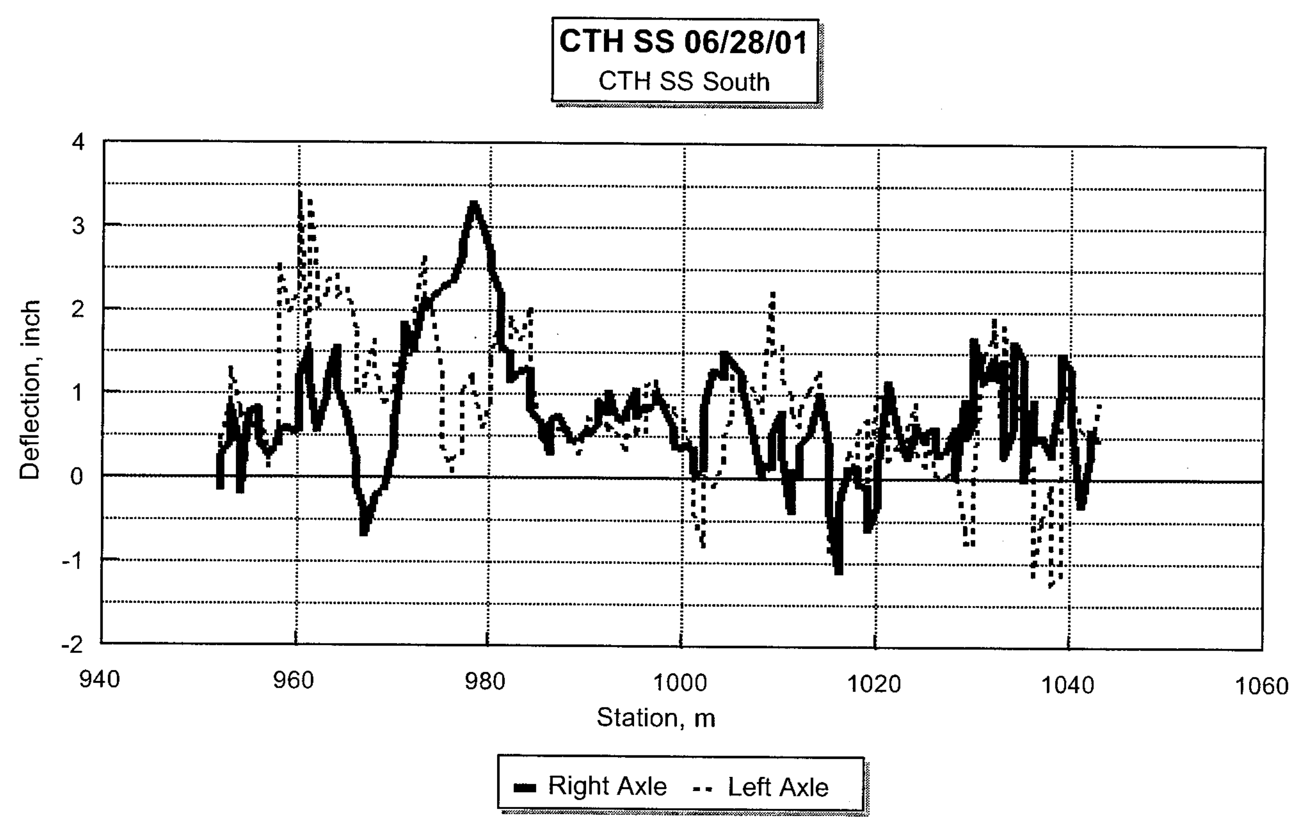

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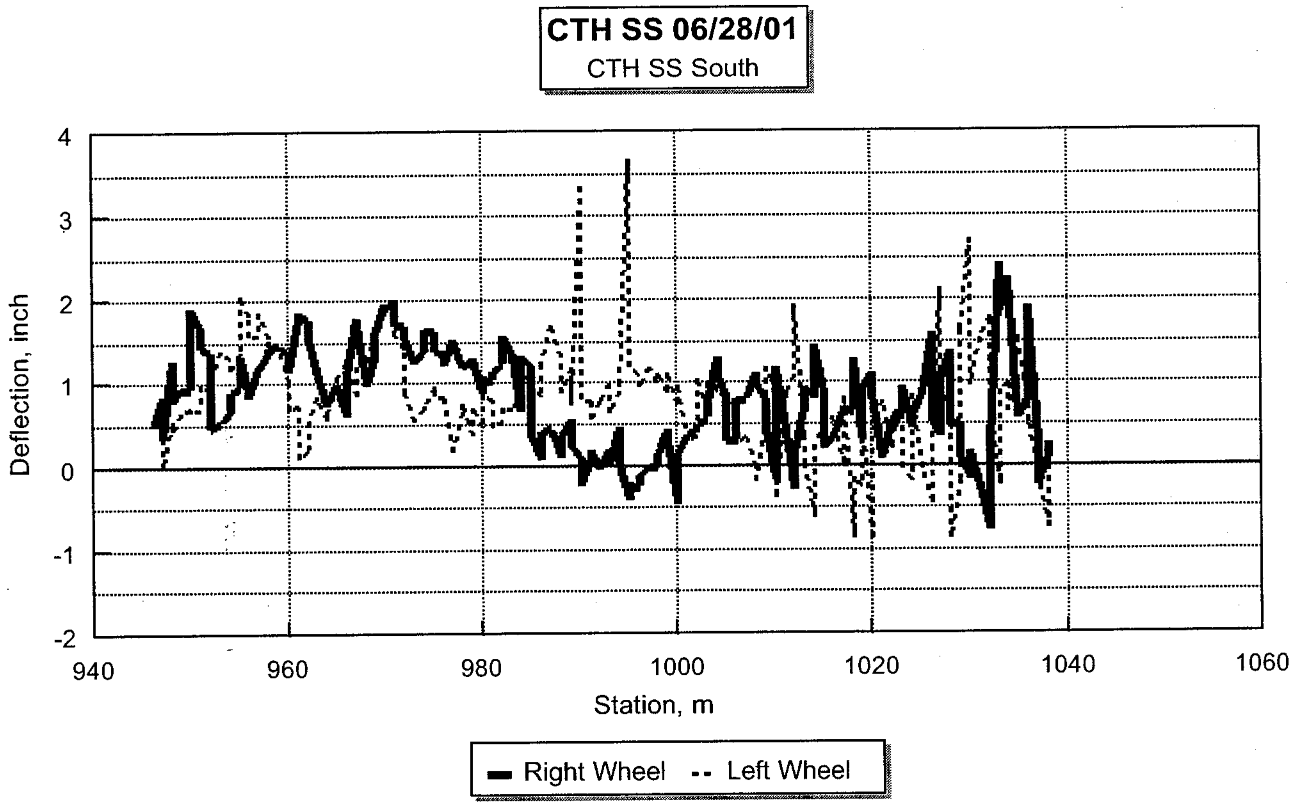

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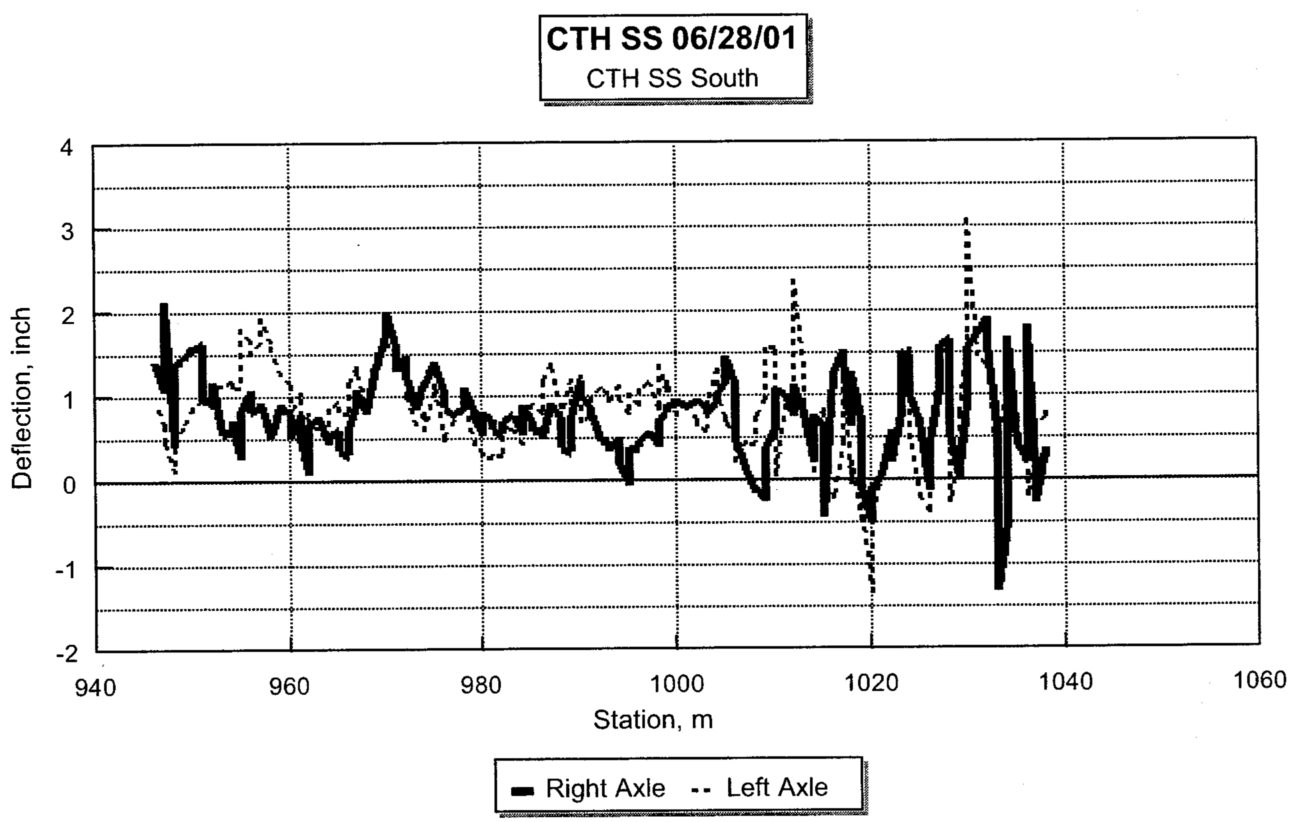

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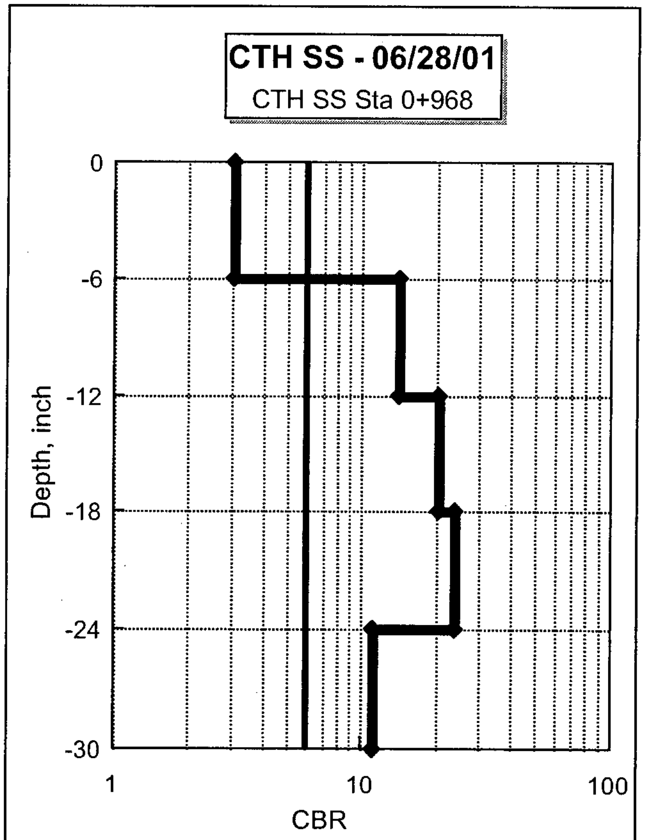

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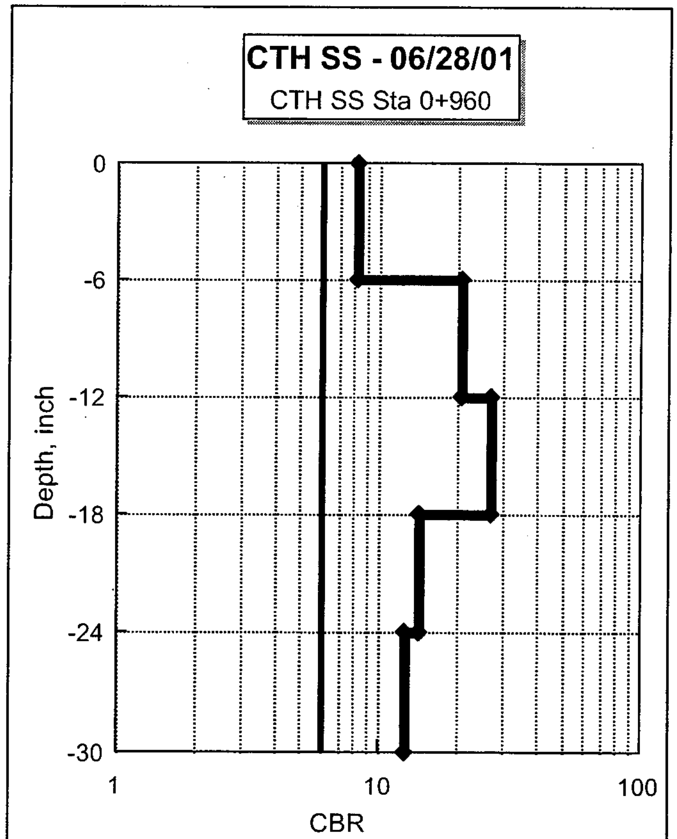

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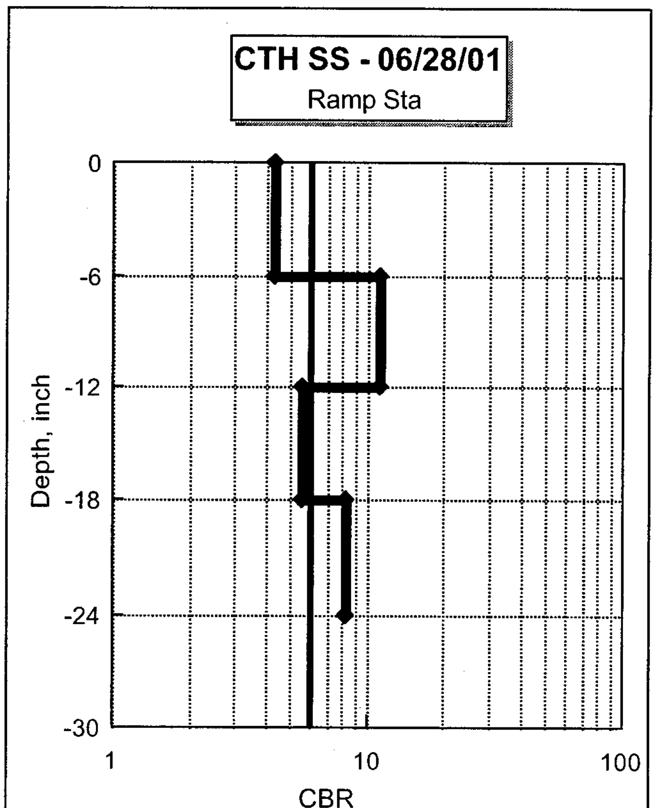

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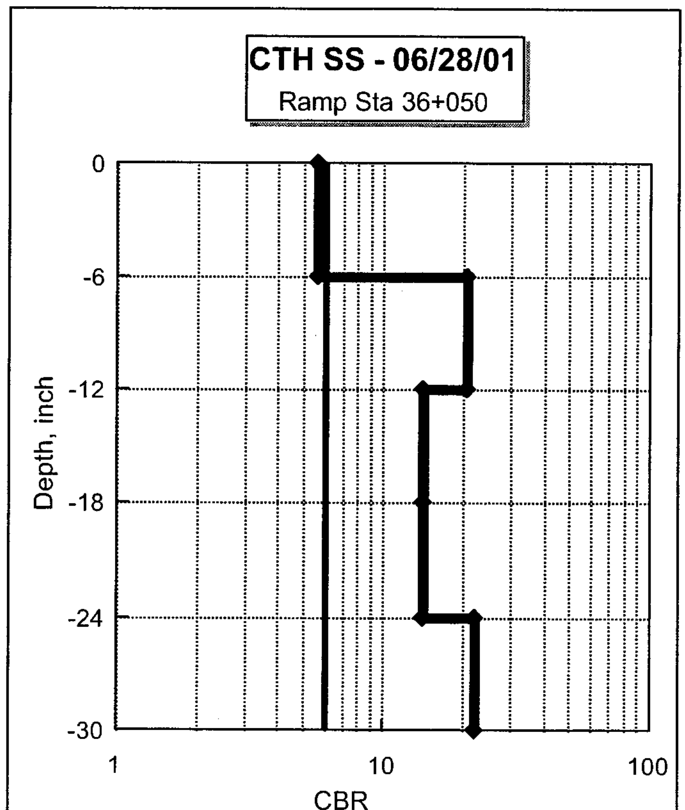

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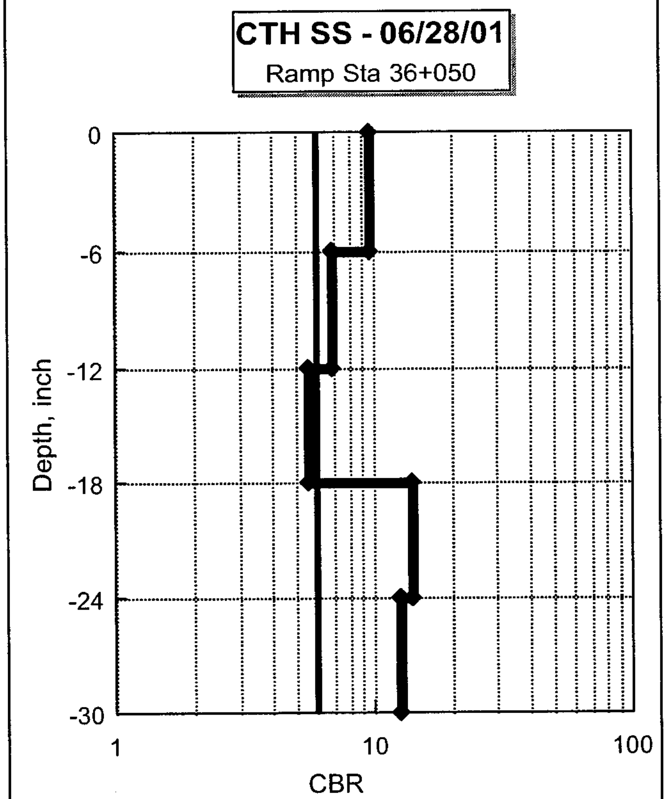

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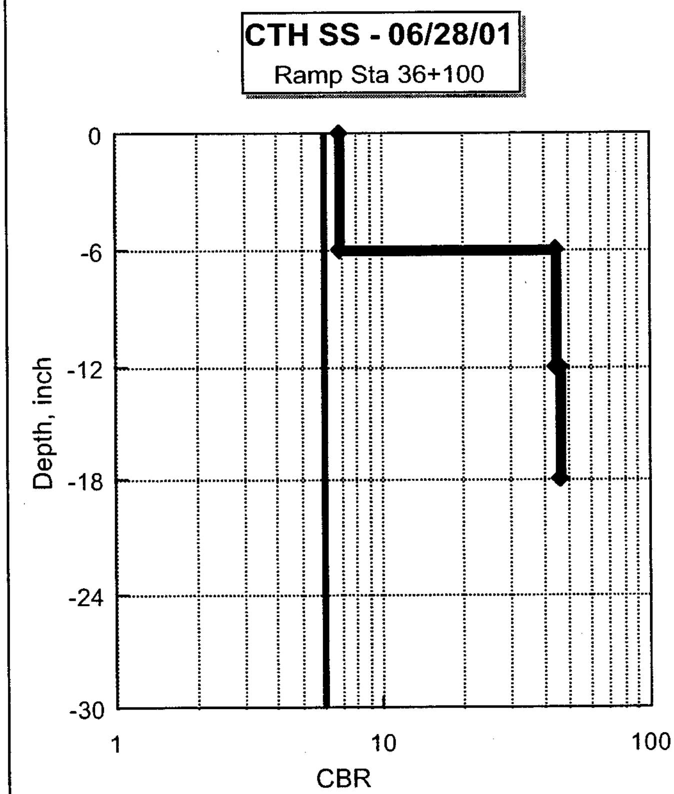

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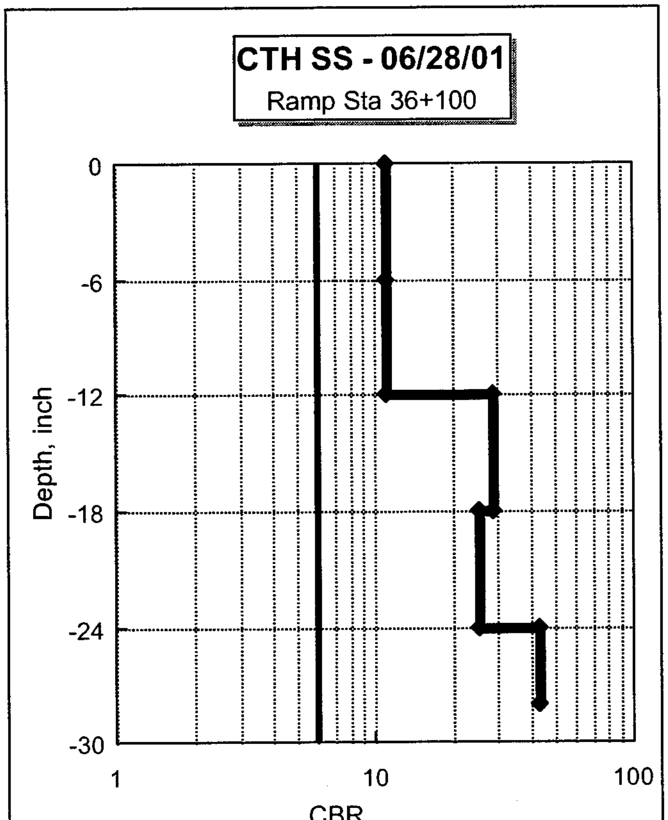
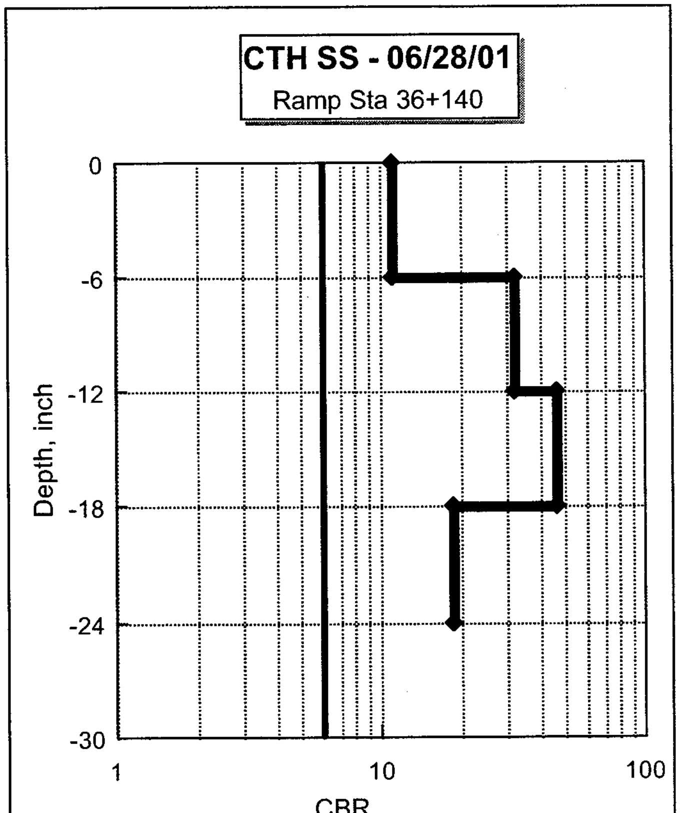


Figure 2.1.46



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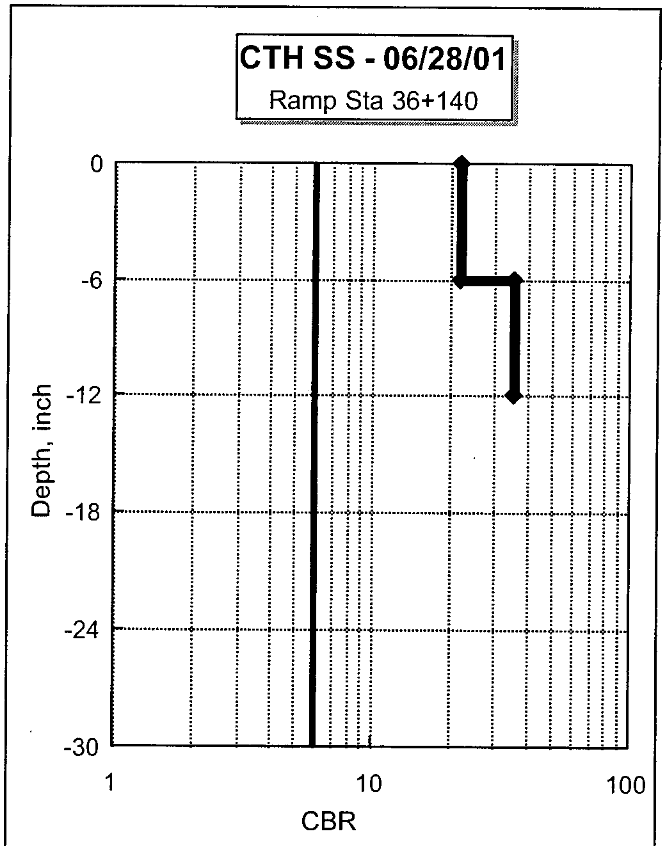

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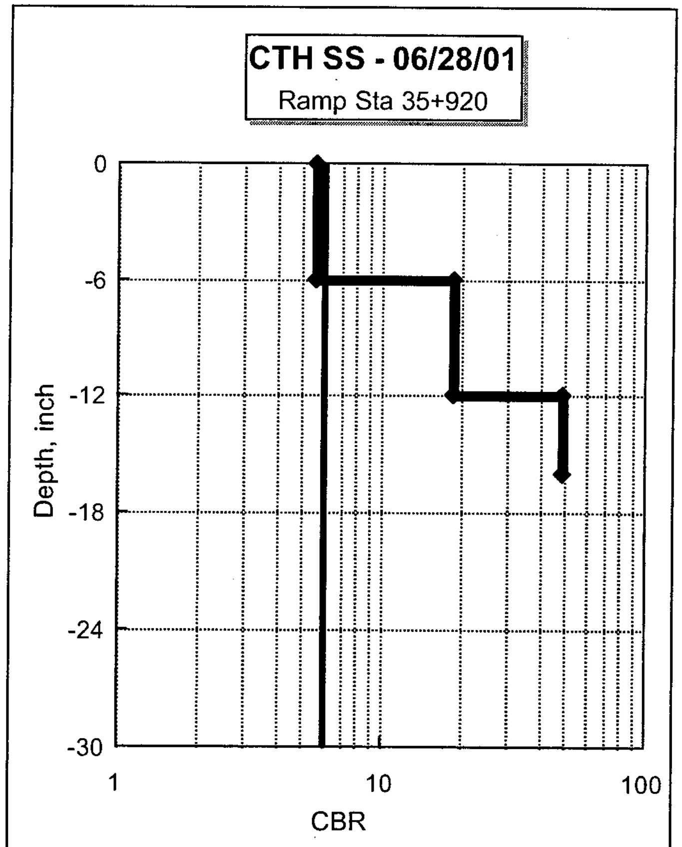

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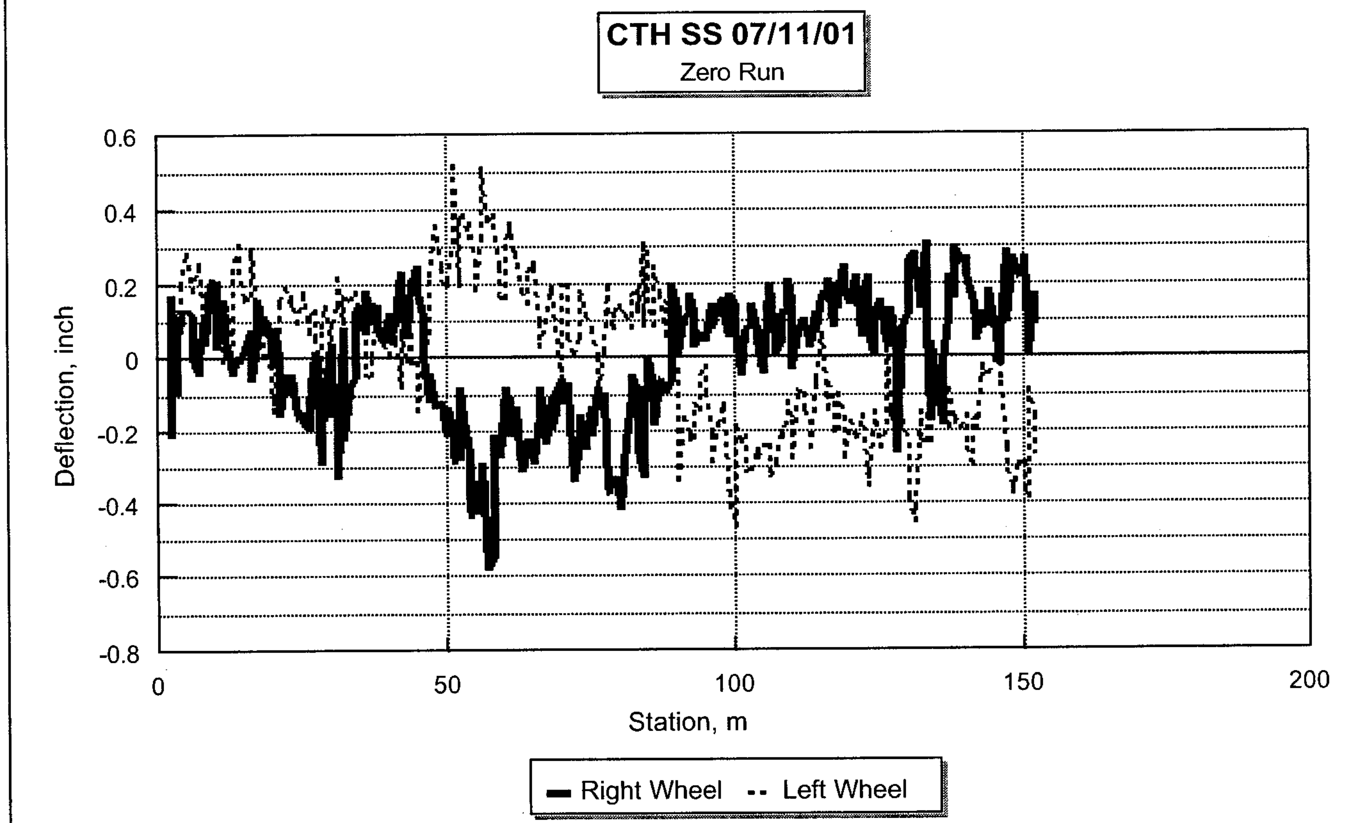
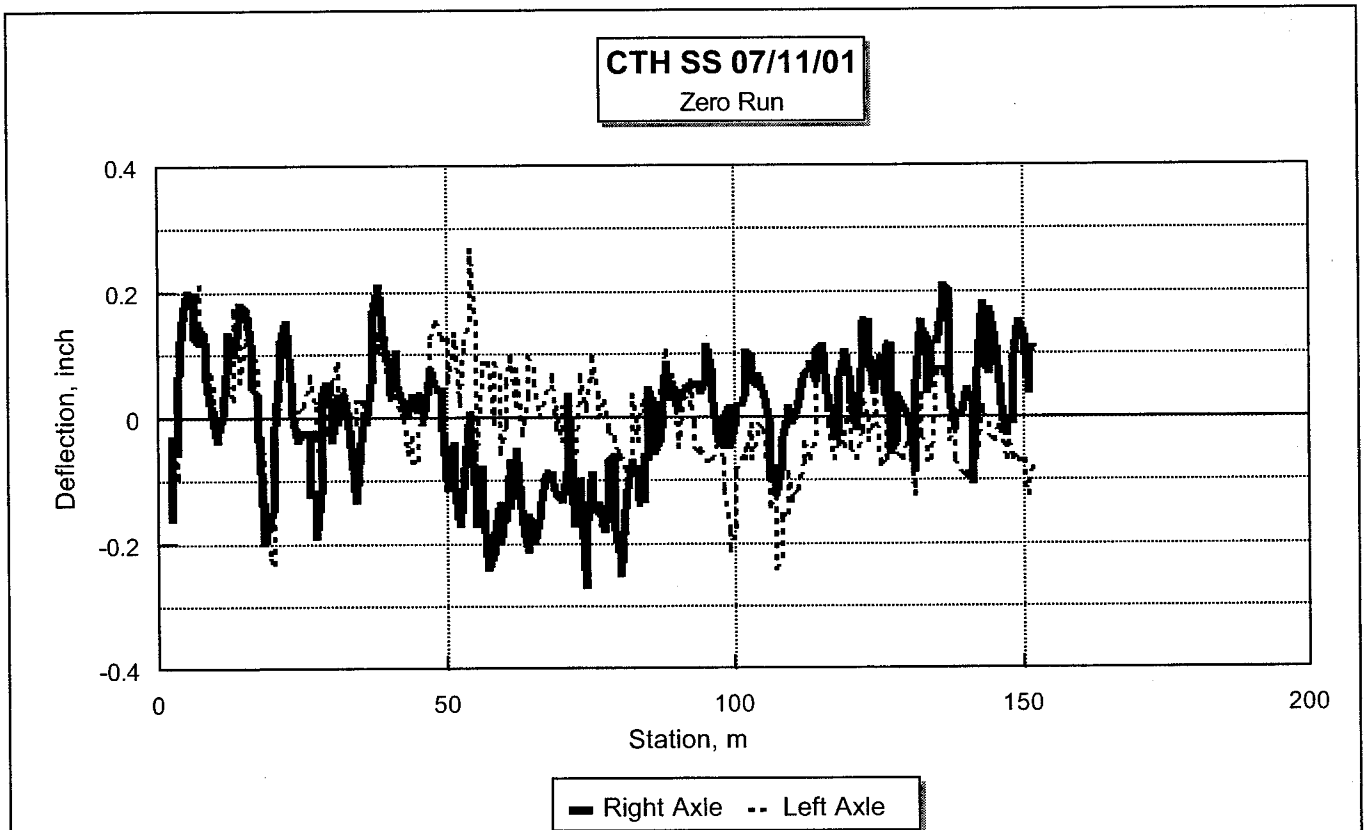


Figure 2.1.50



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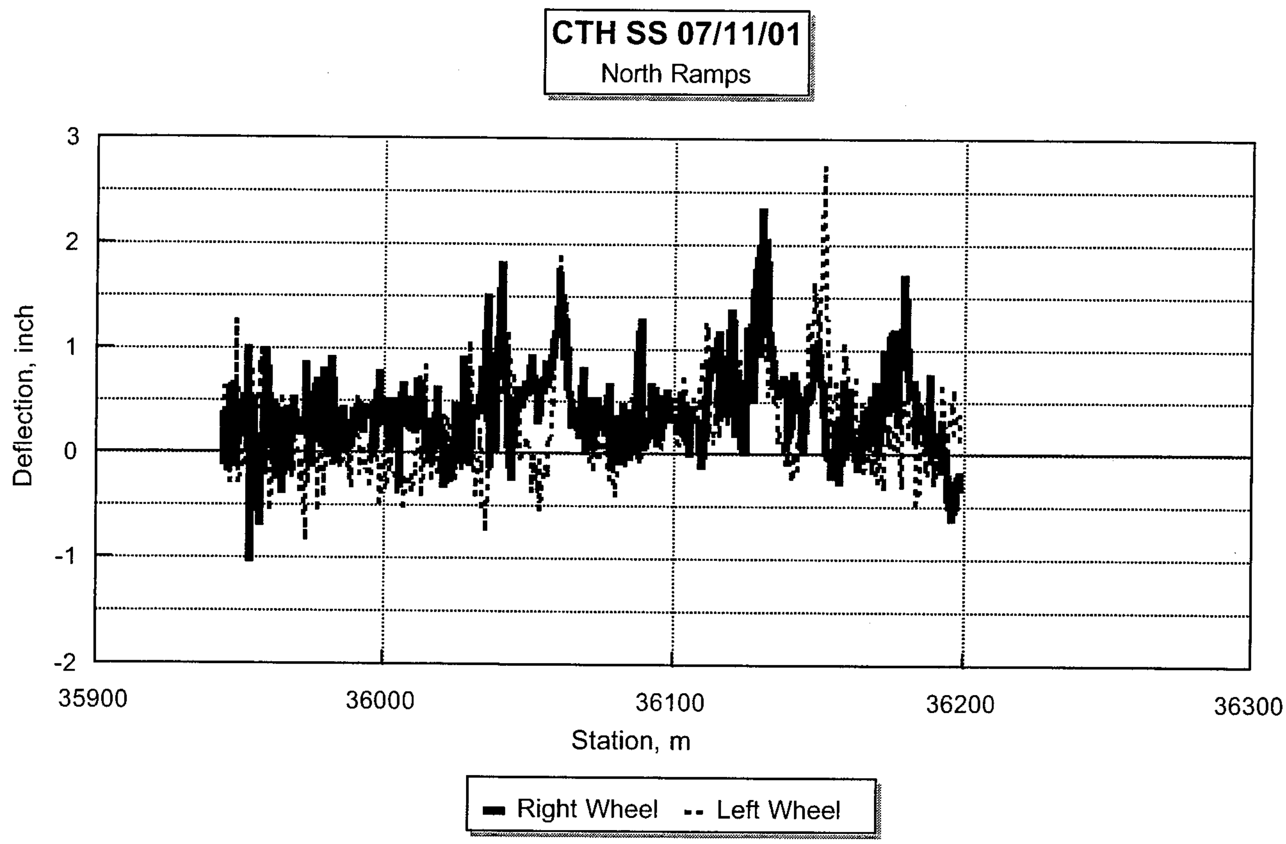

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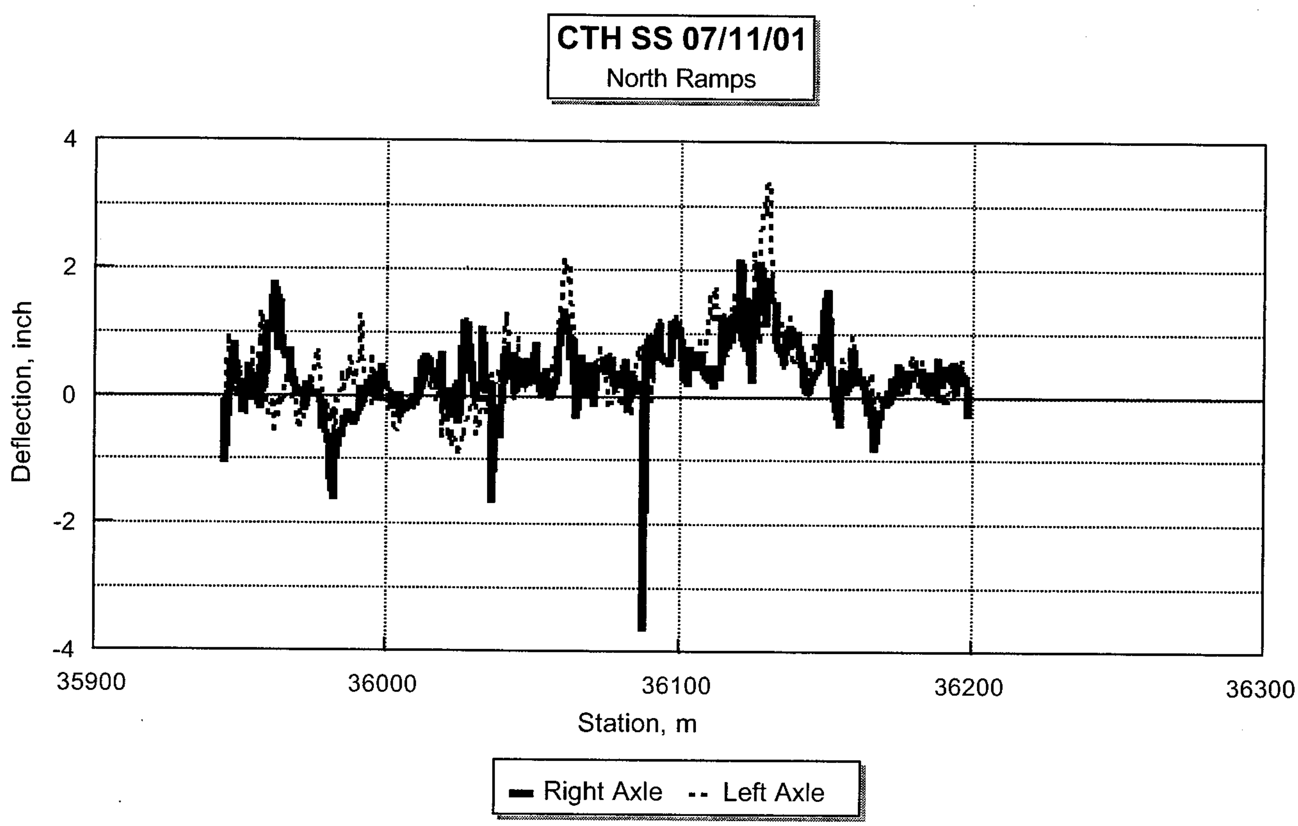

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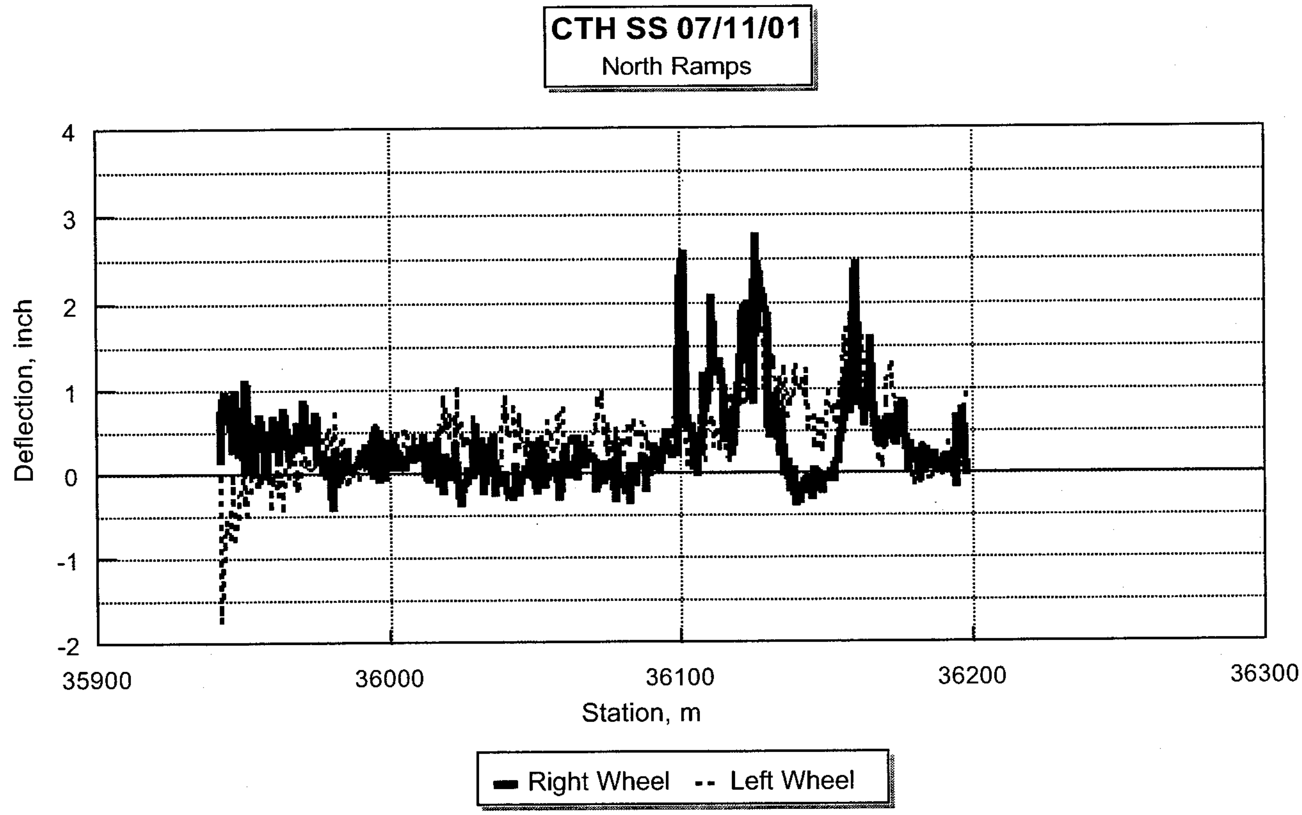

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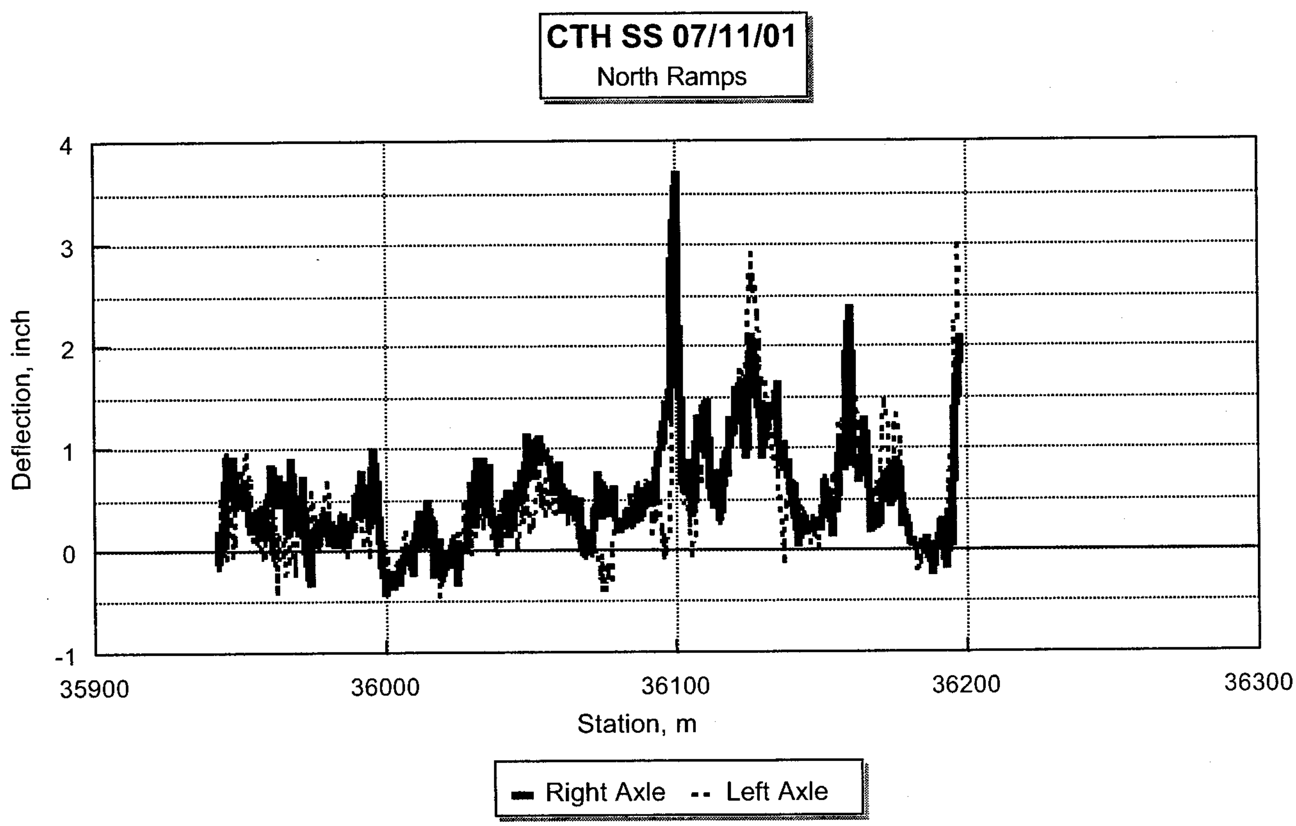

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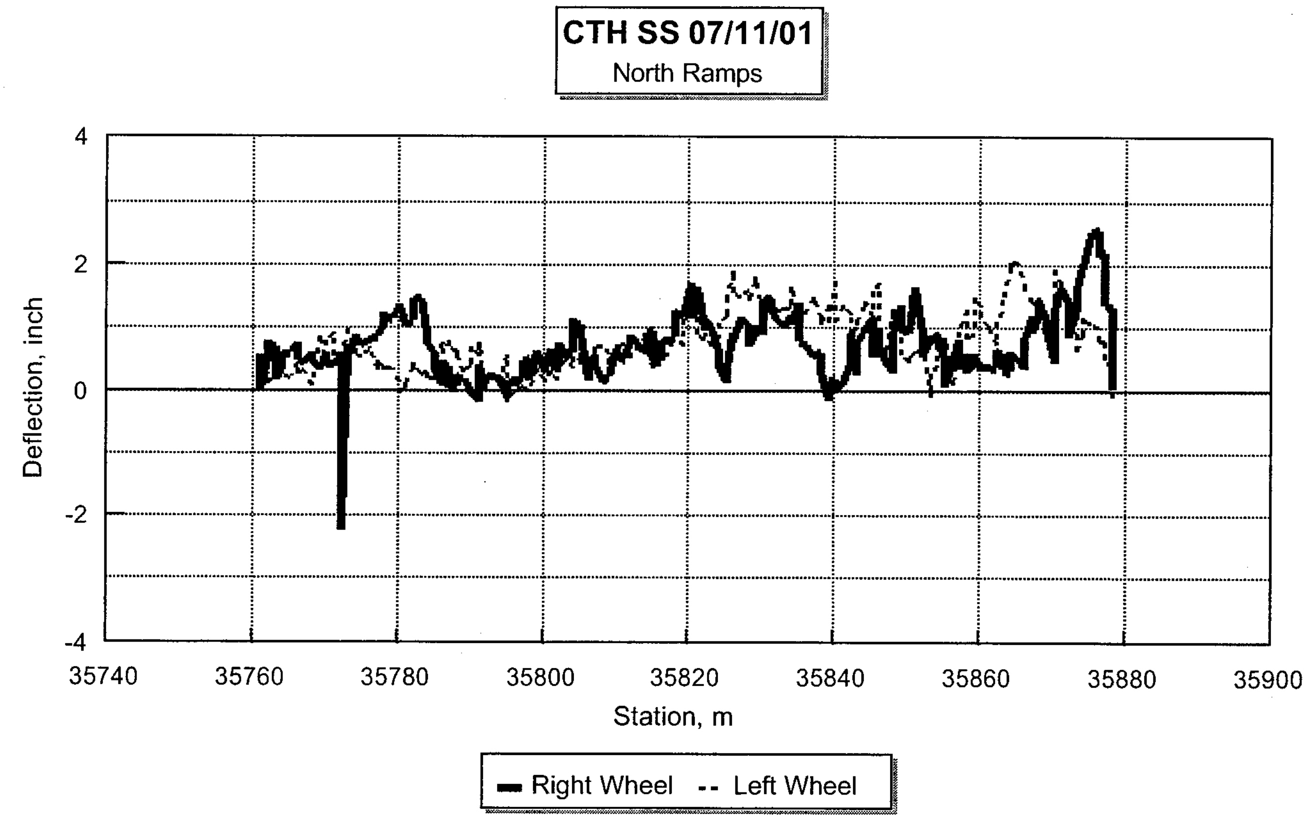

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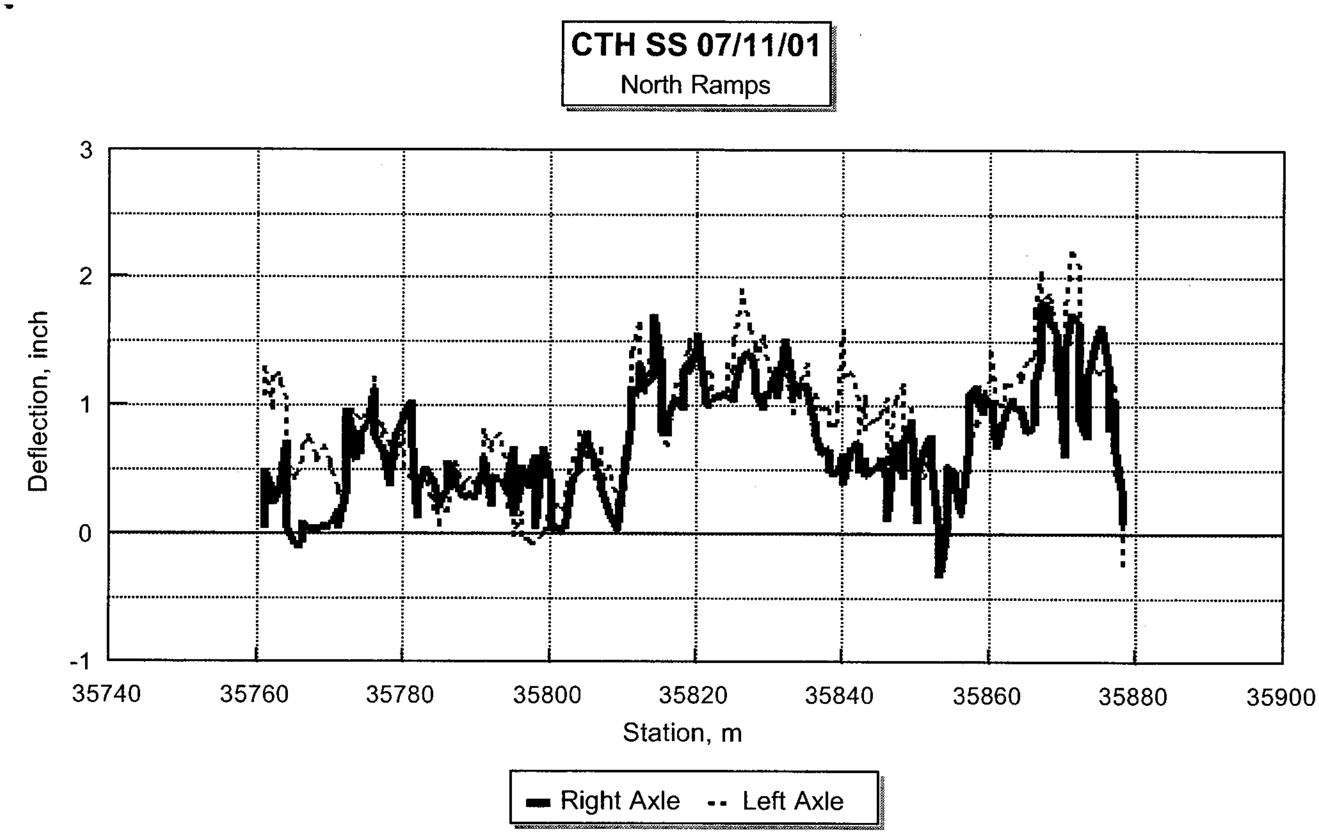

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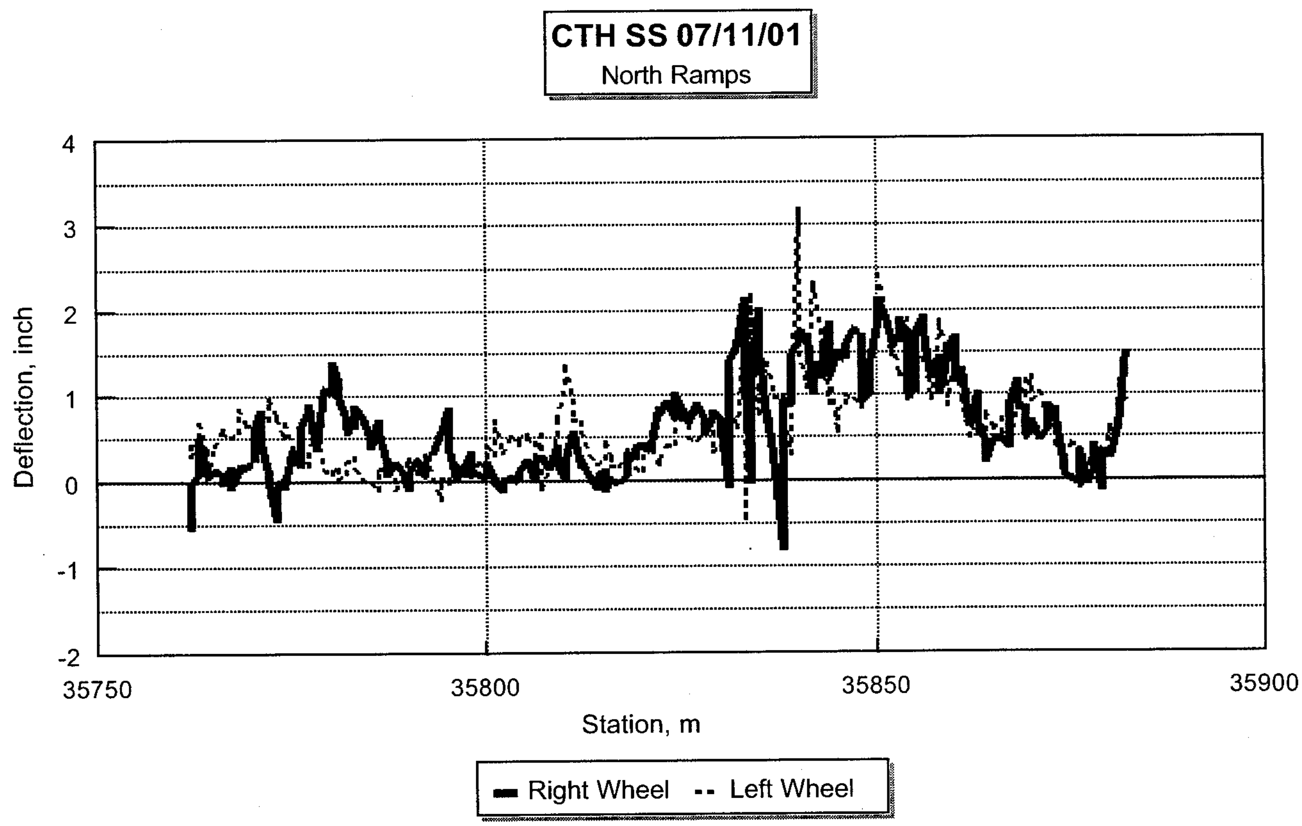
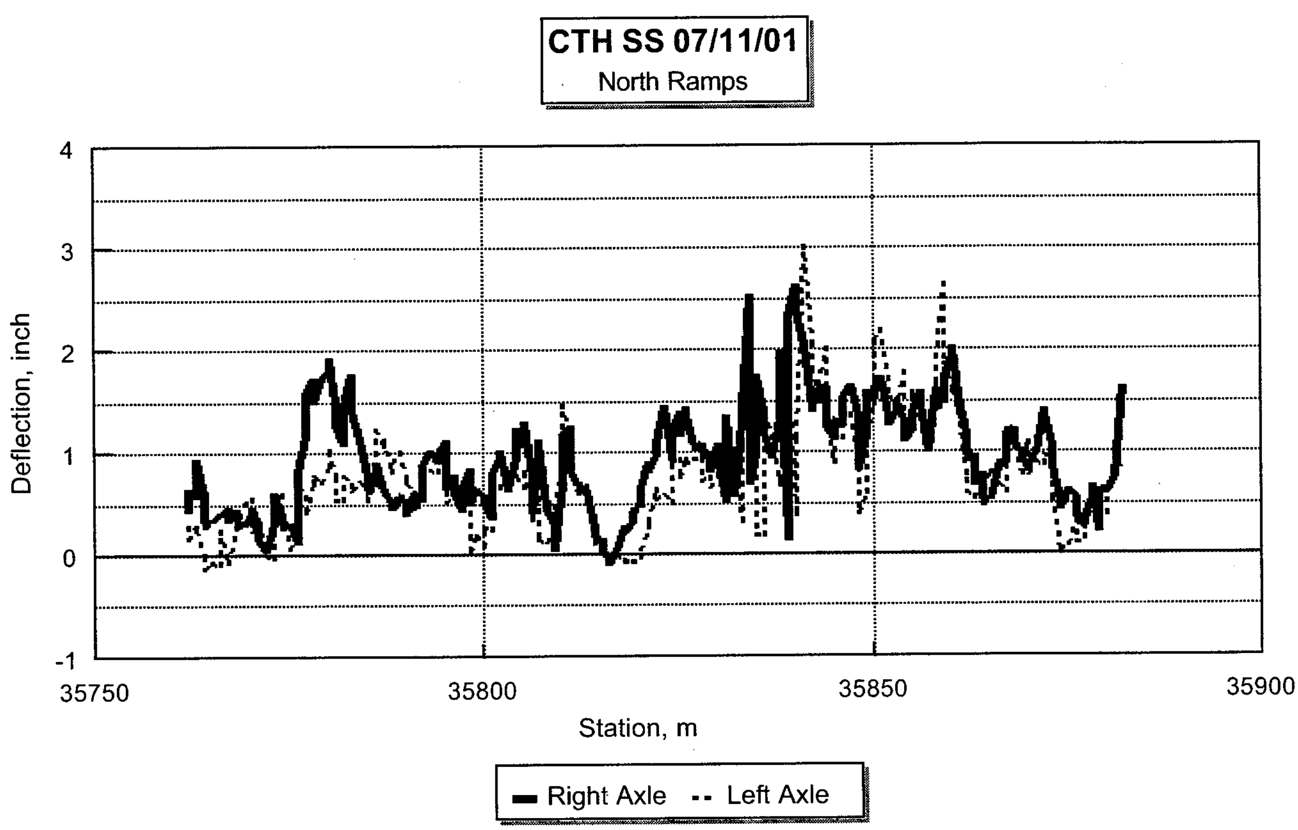


Figure 2.1.58



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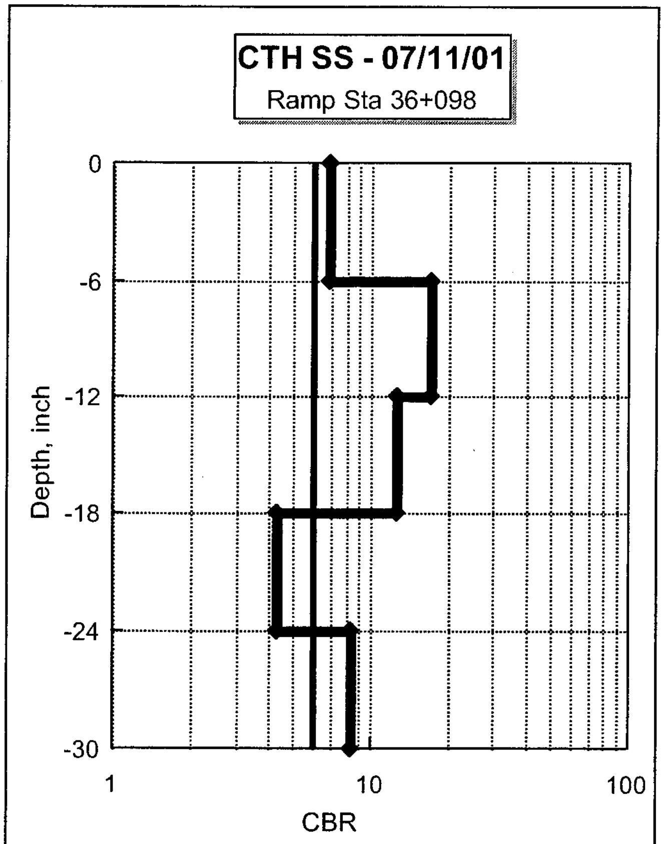

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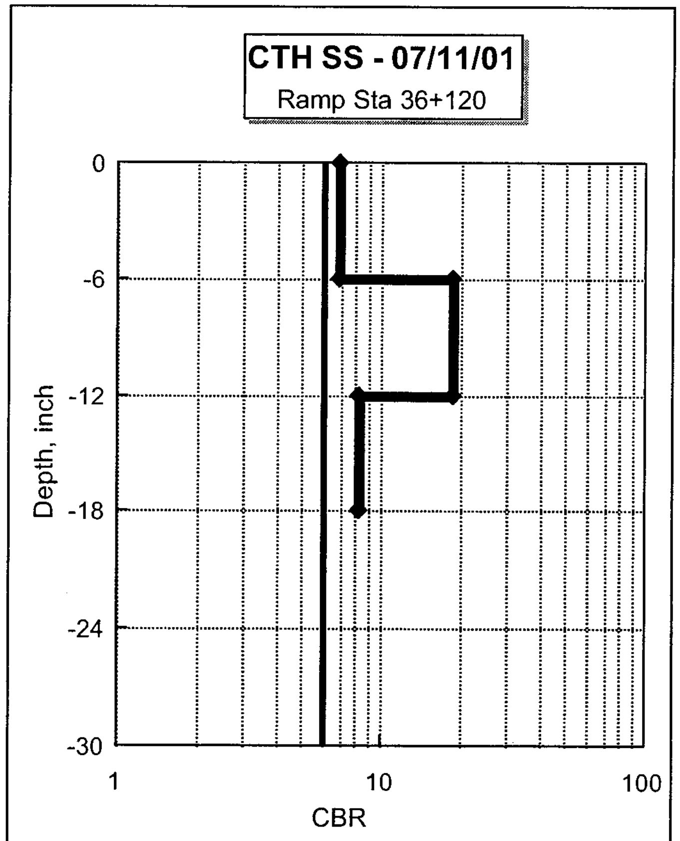

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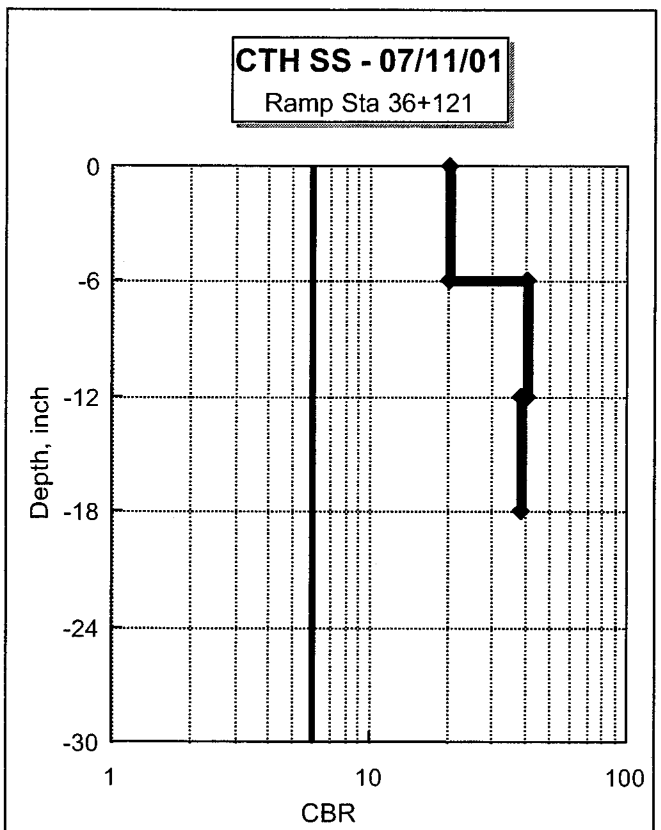


Figure 2.1.62

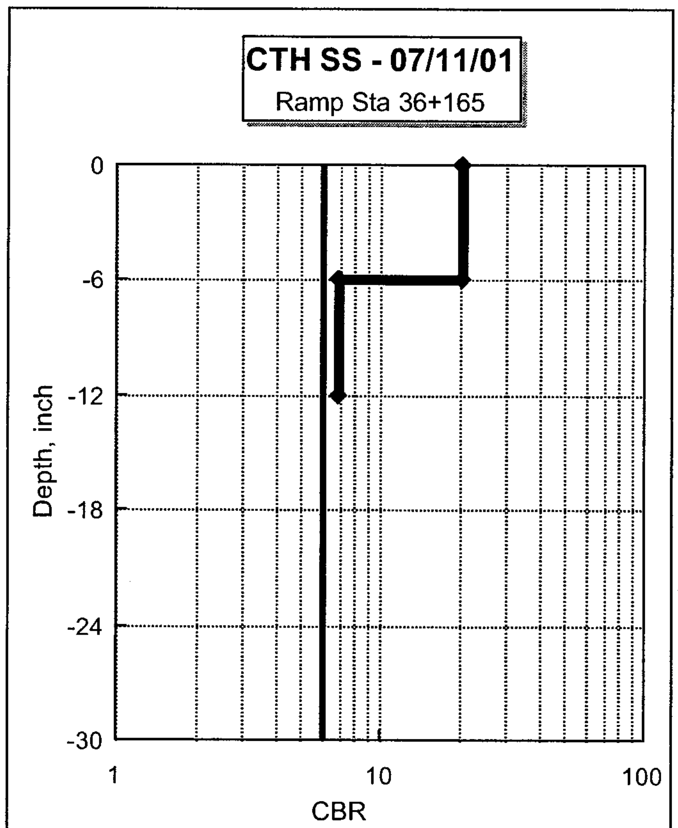
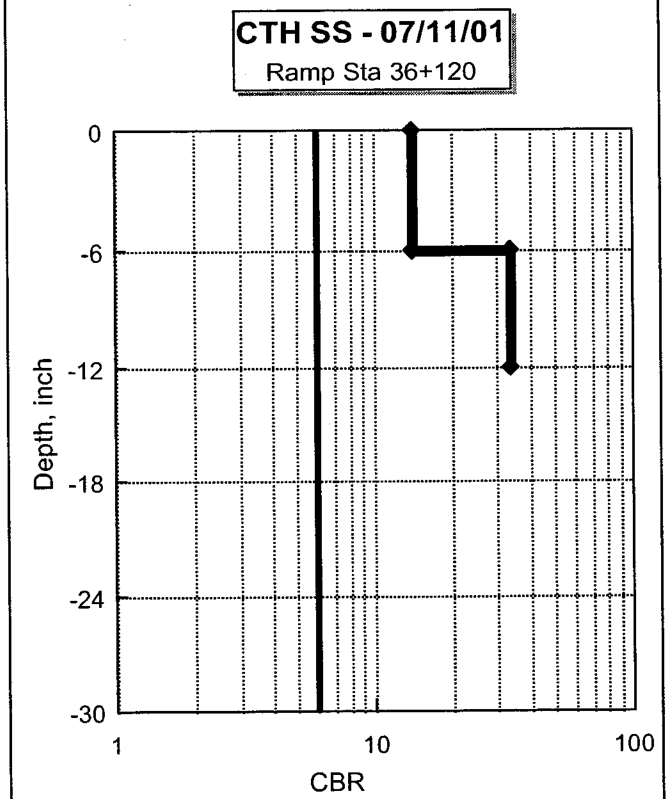


Figure 2.1.63


CTH SS - 07/11/01
Ramp Sta 36+120
Depth, inch
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-12
-18
-24
-30
1
10
100
CBR

Figure 2.1.64

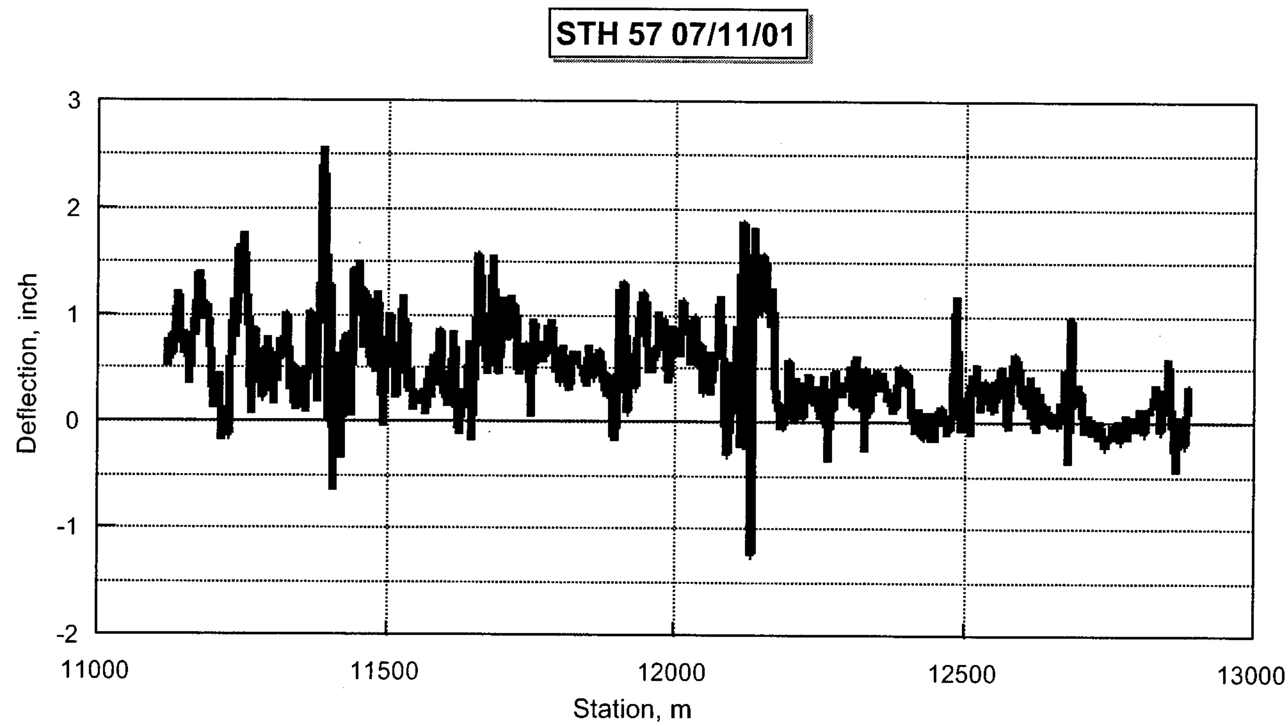


Figure 2.2.1

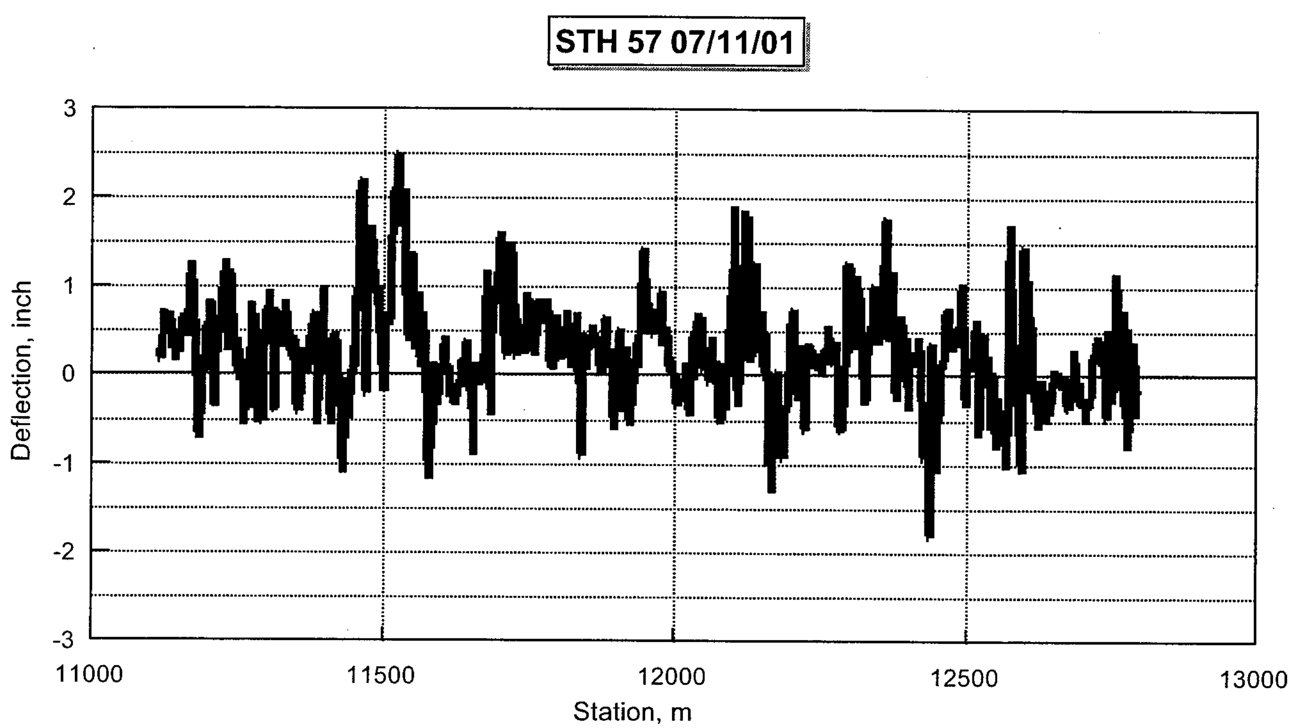


Figure 2.2.2

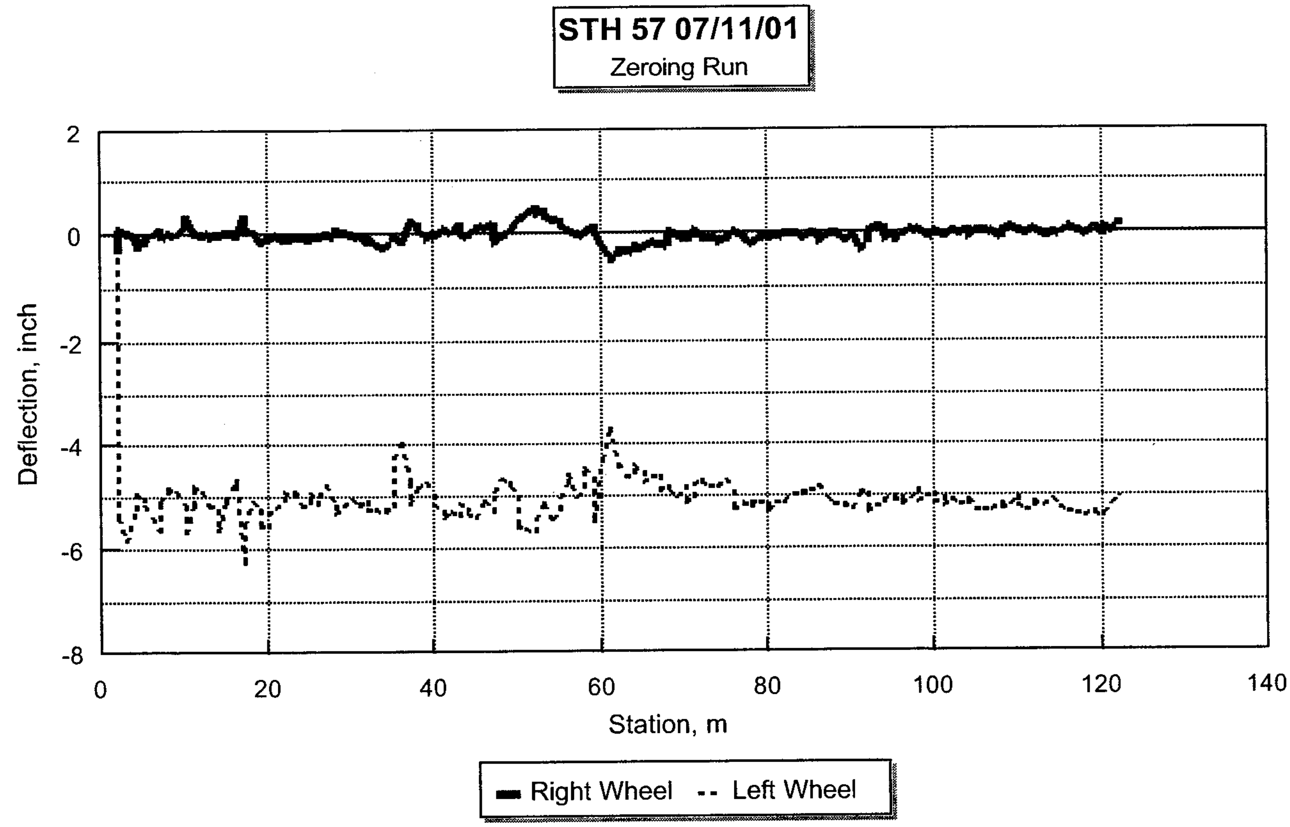
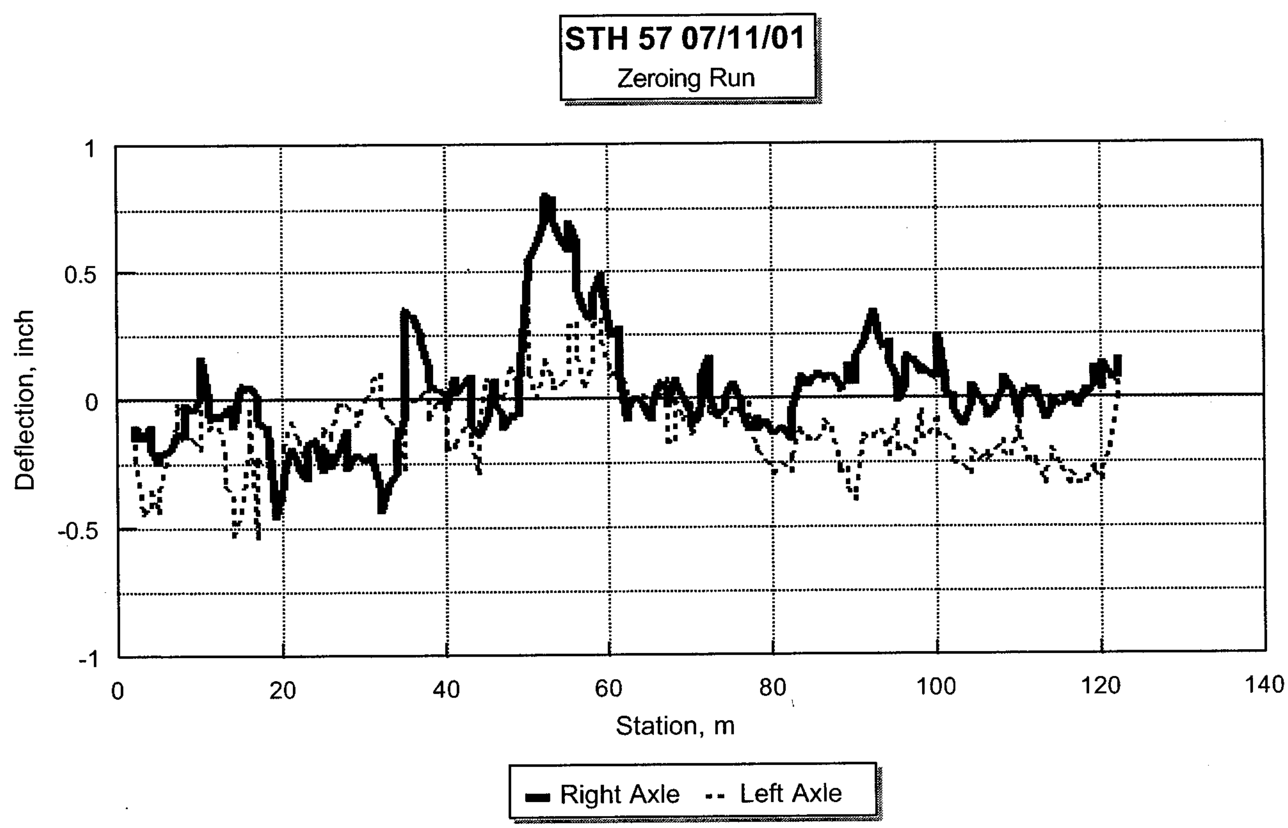


Figure 2.2.3



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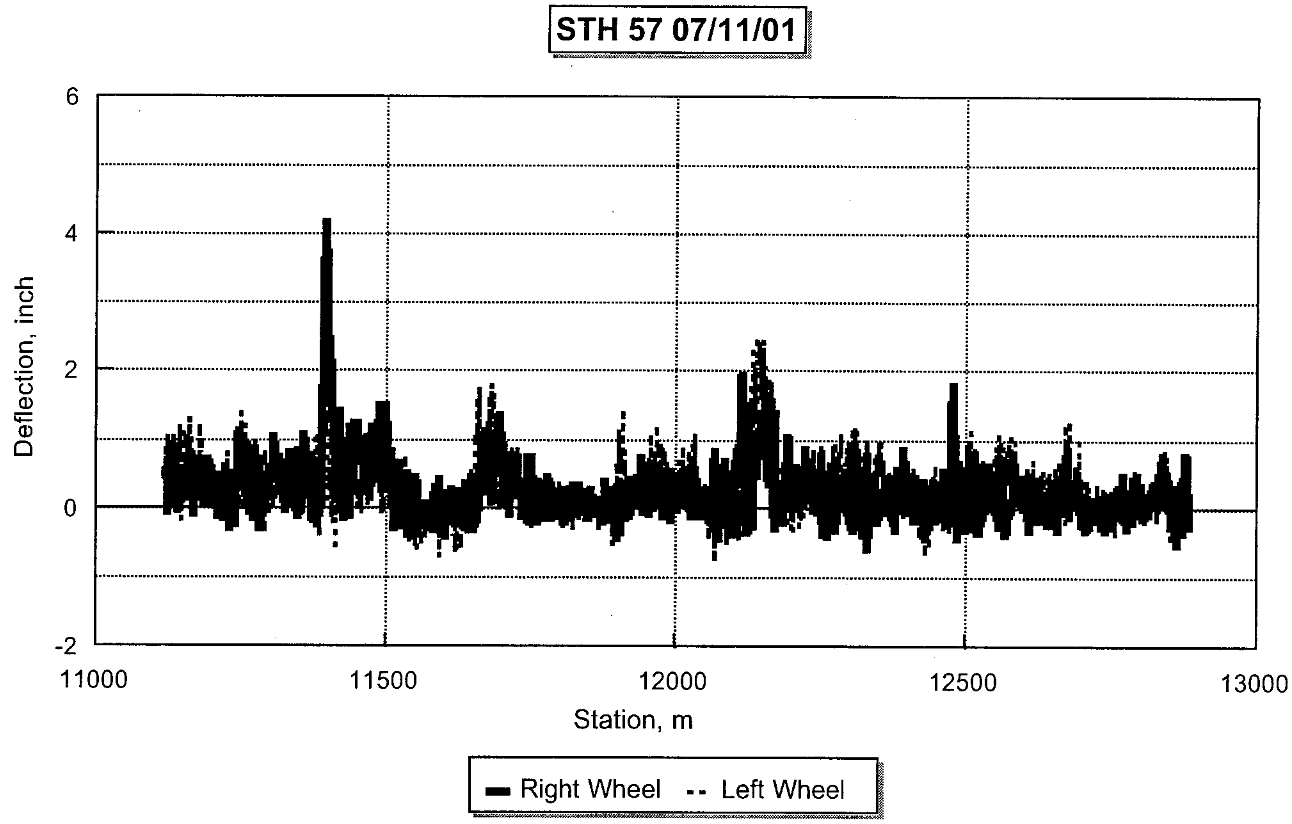

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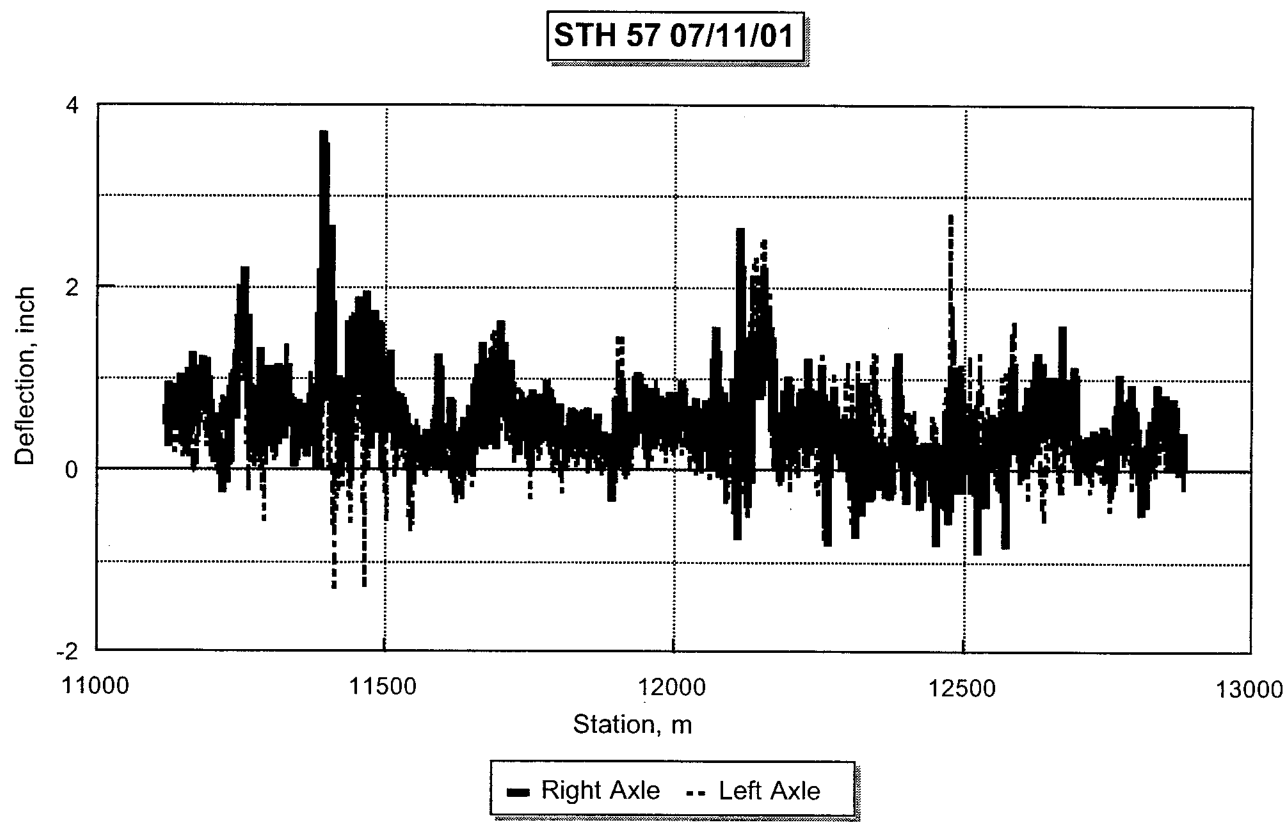

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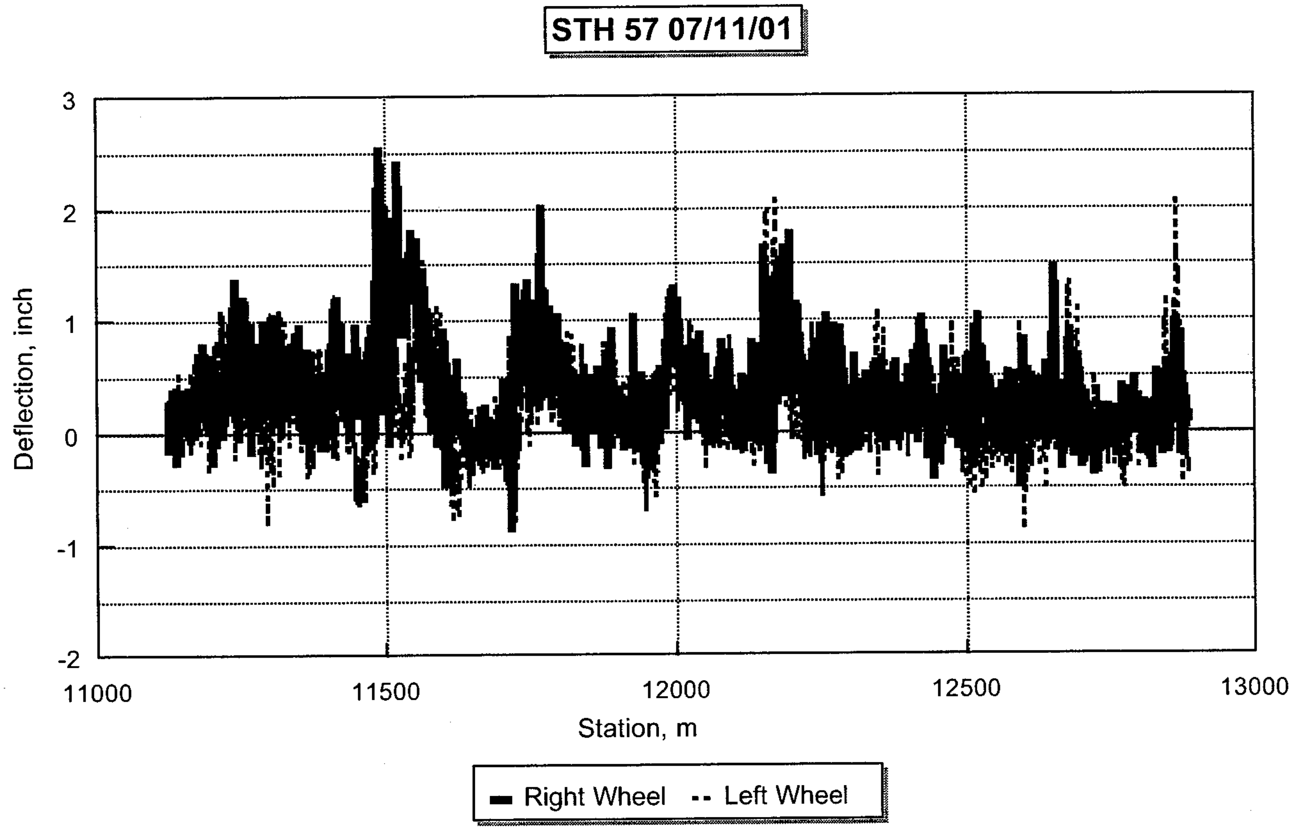

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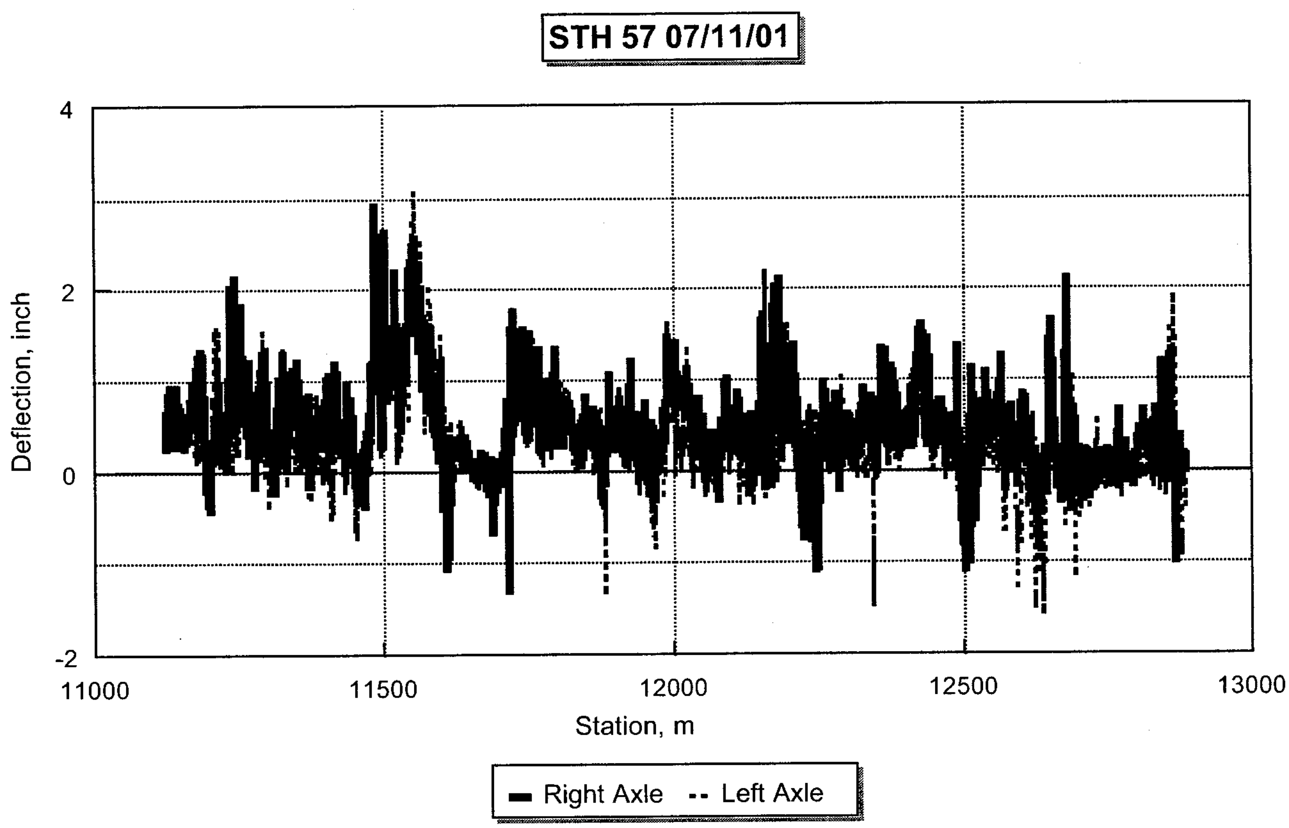

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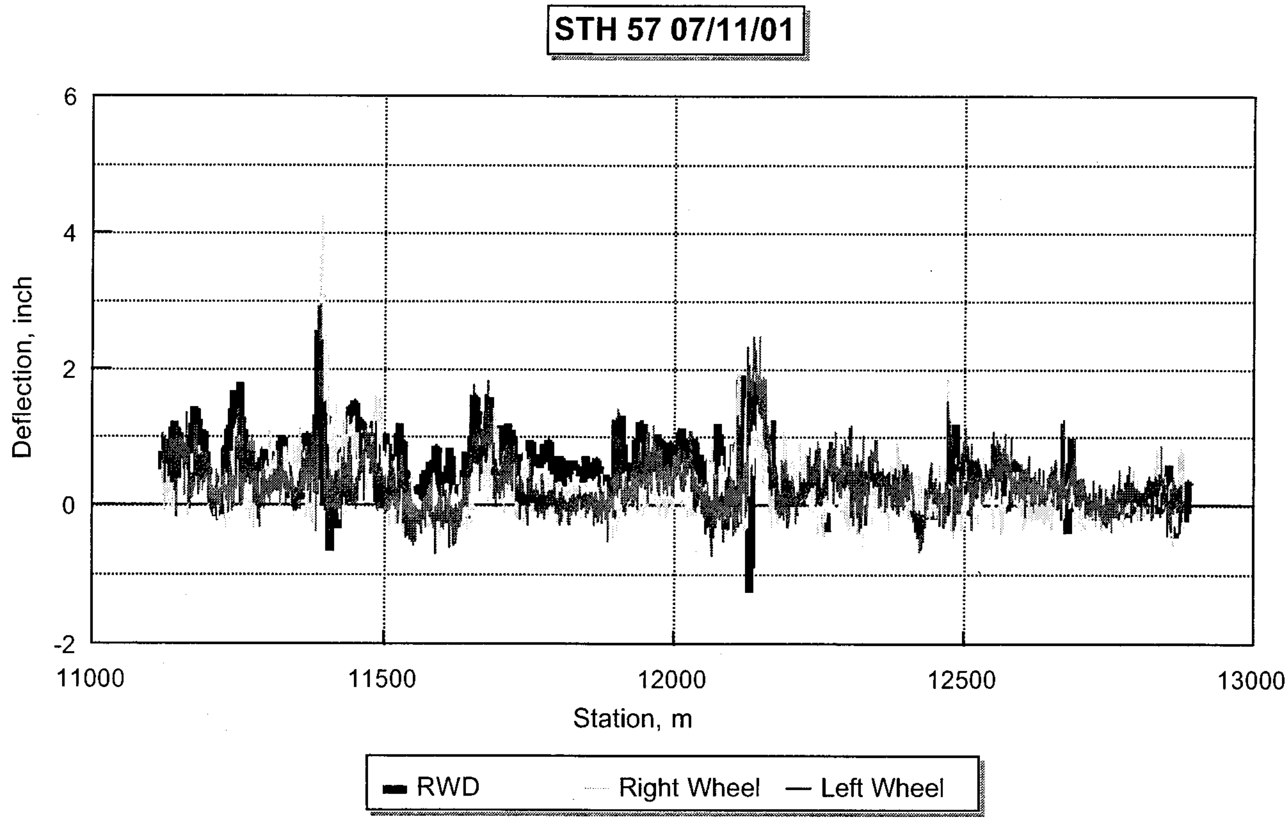

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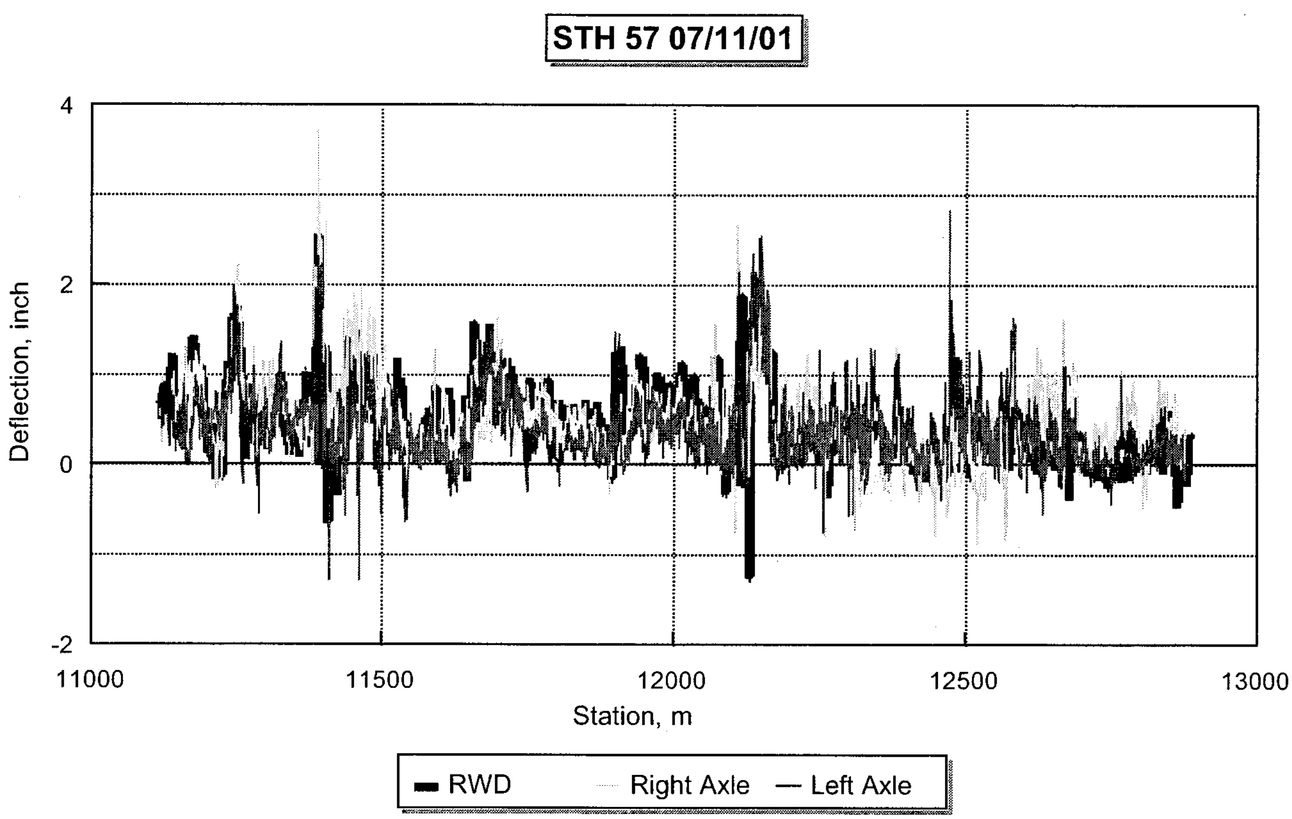

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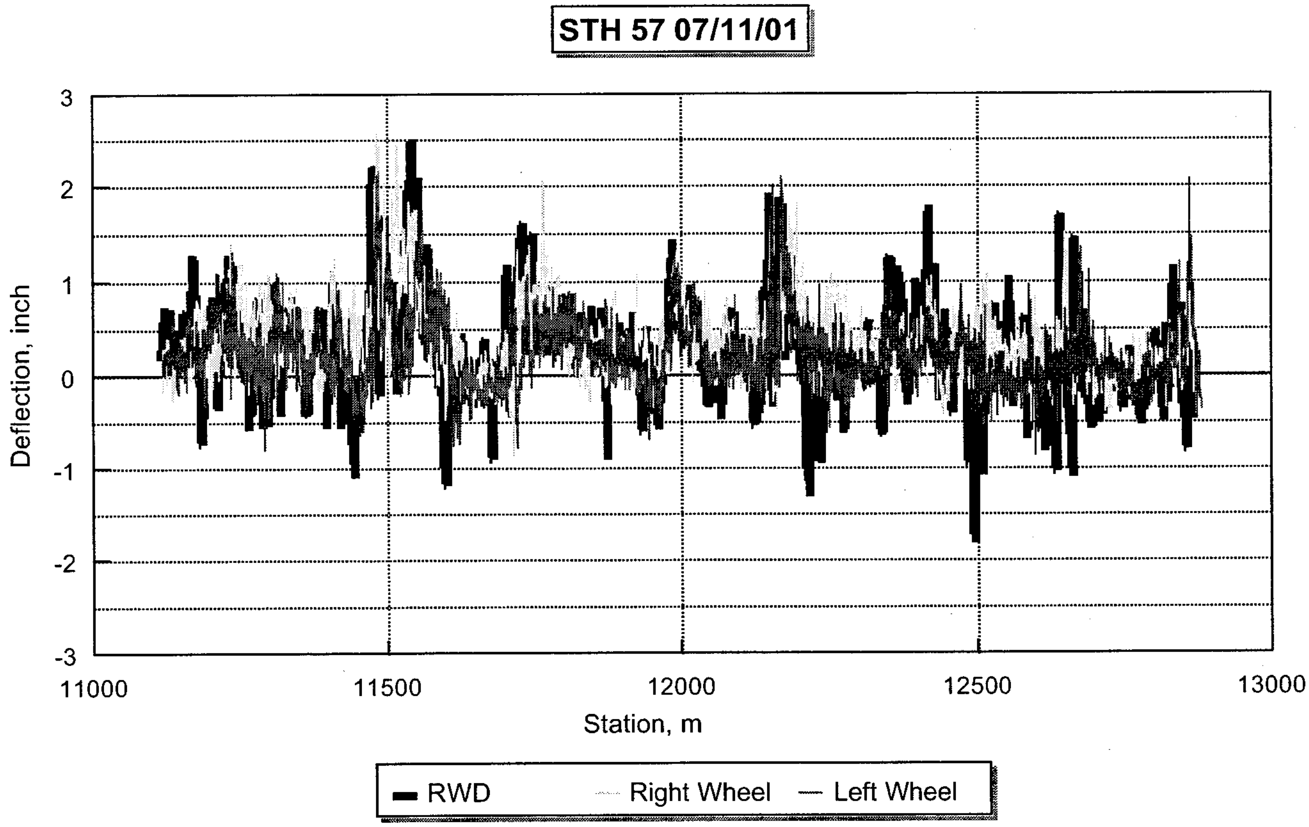

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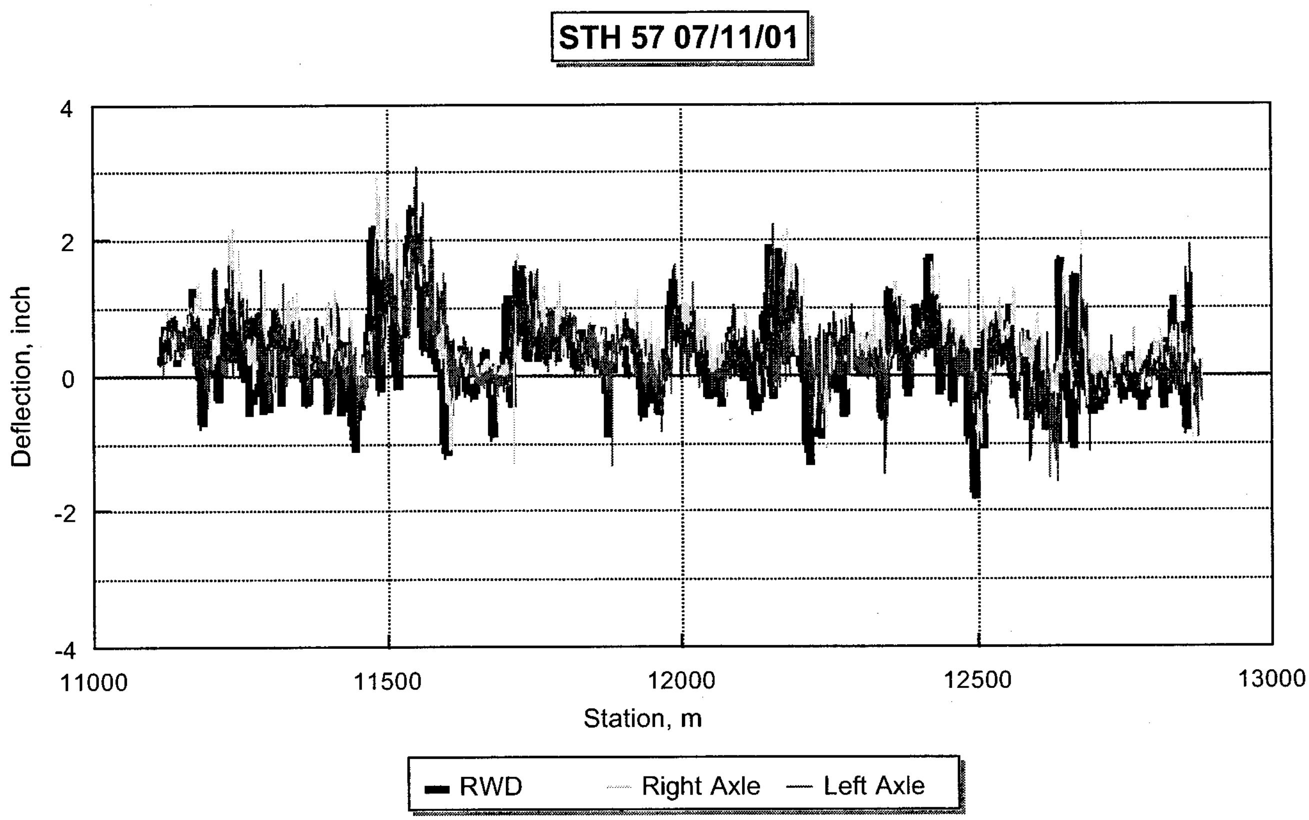

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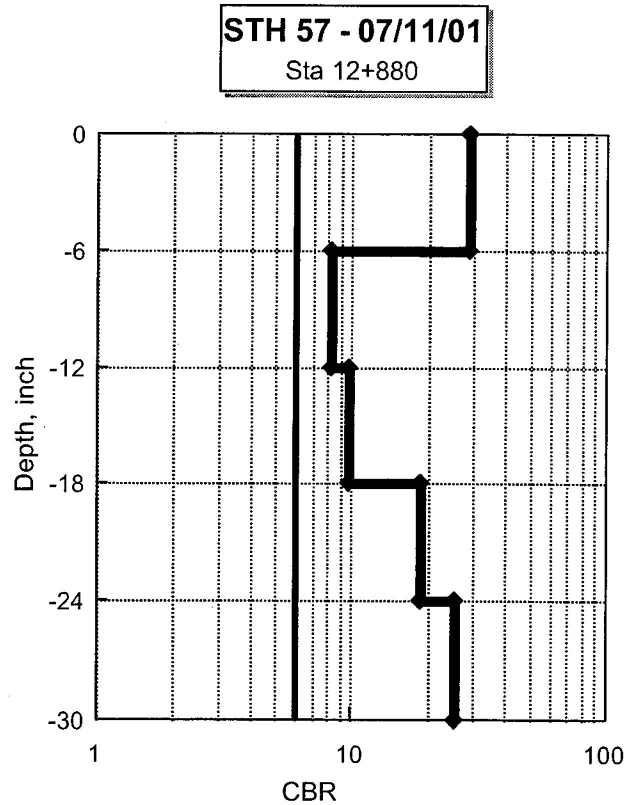

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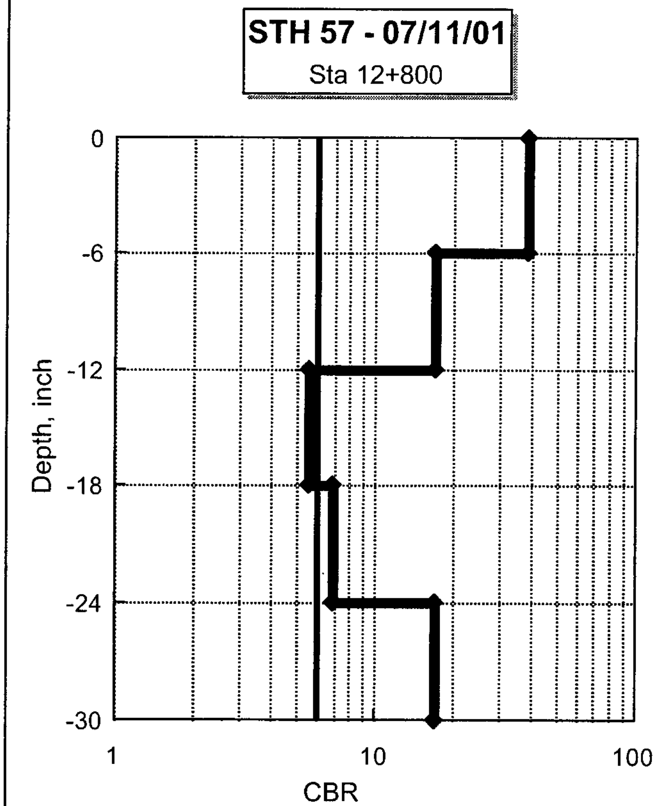

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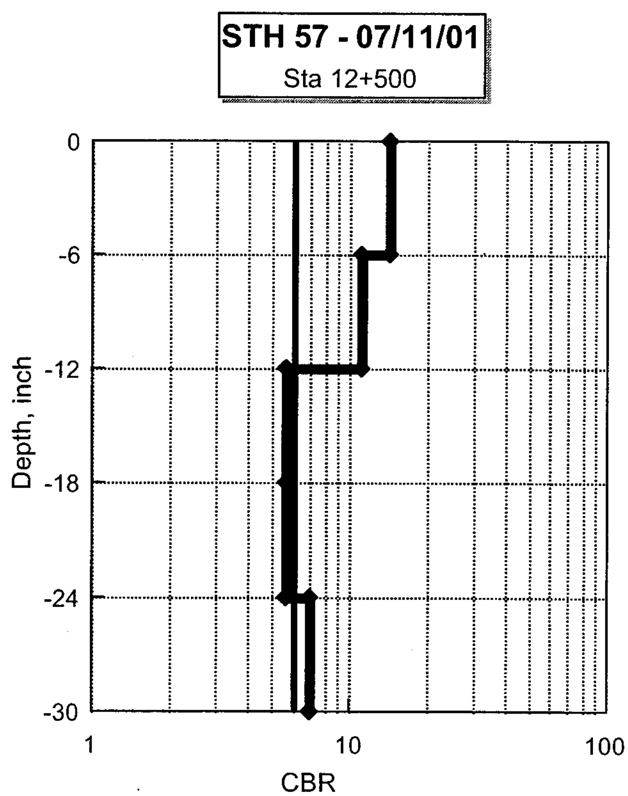

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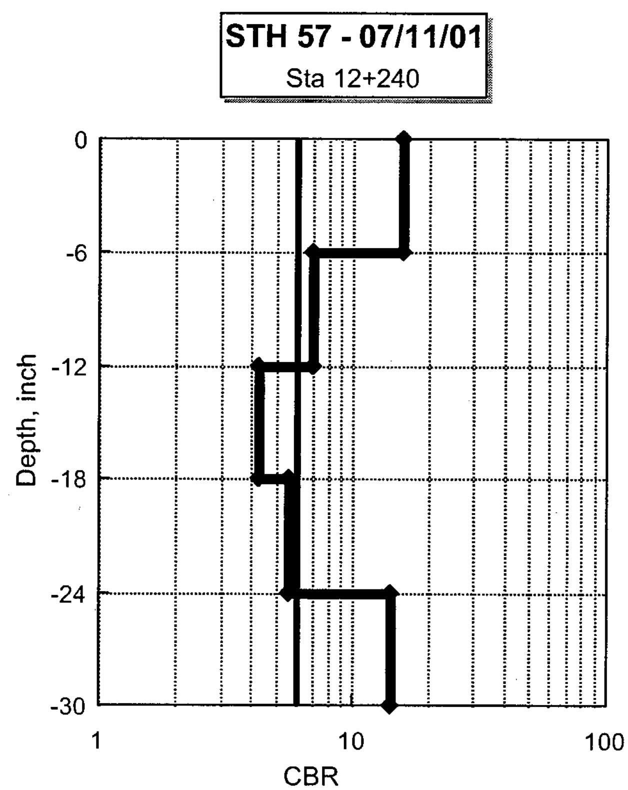

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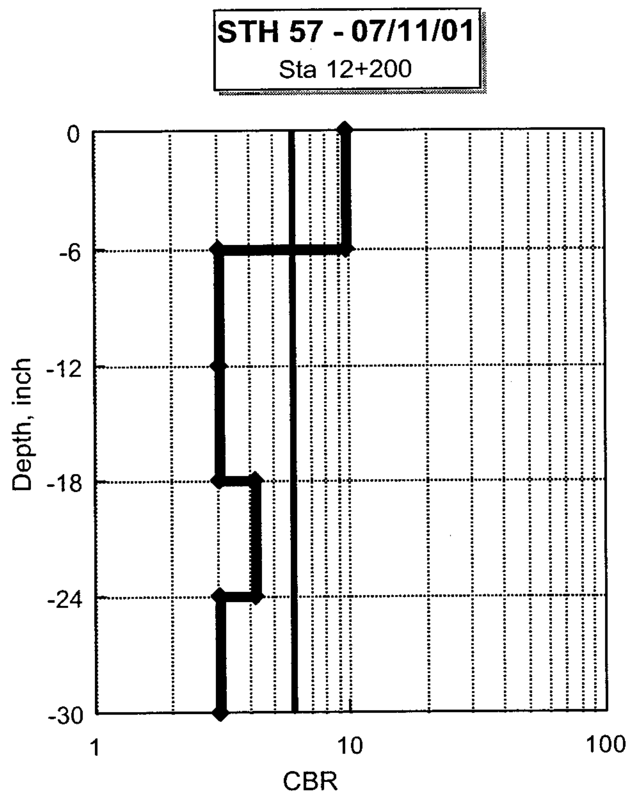

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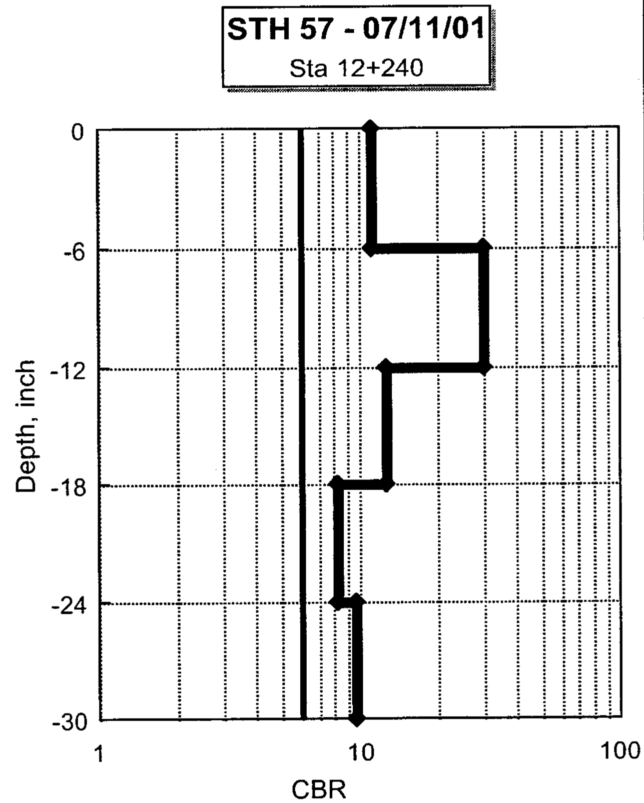

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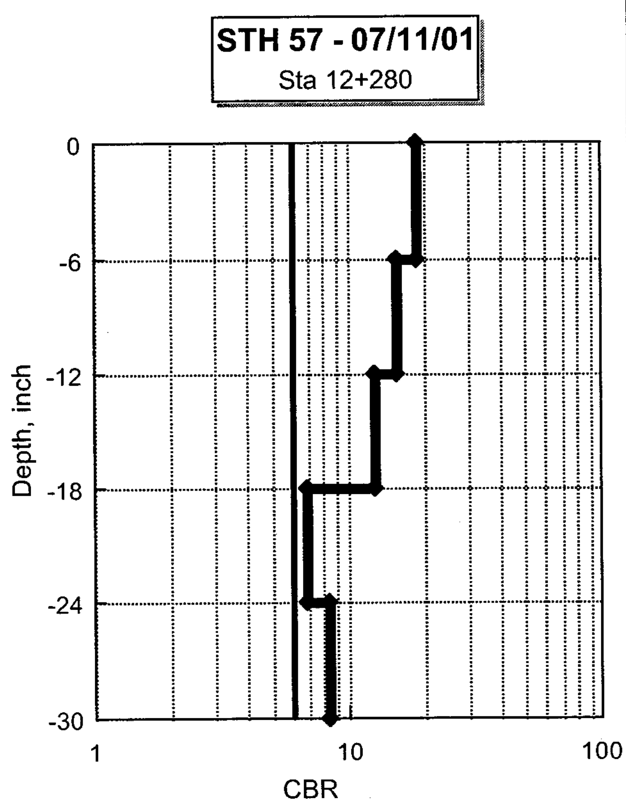

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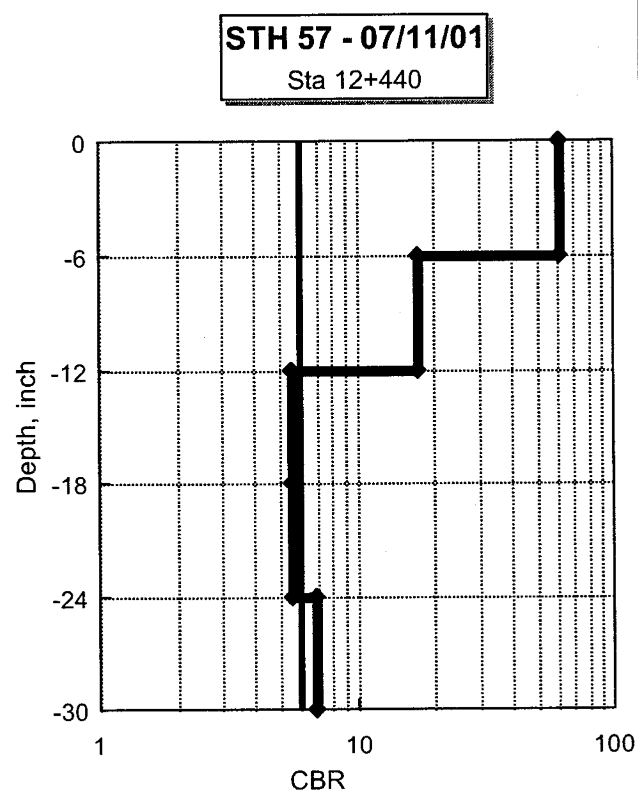

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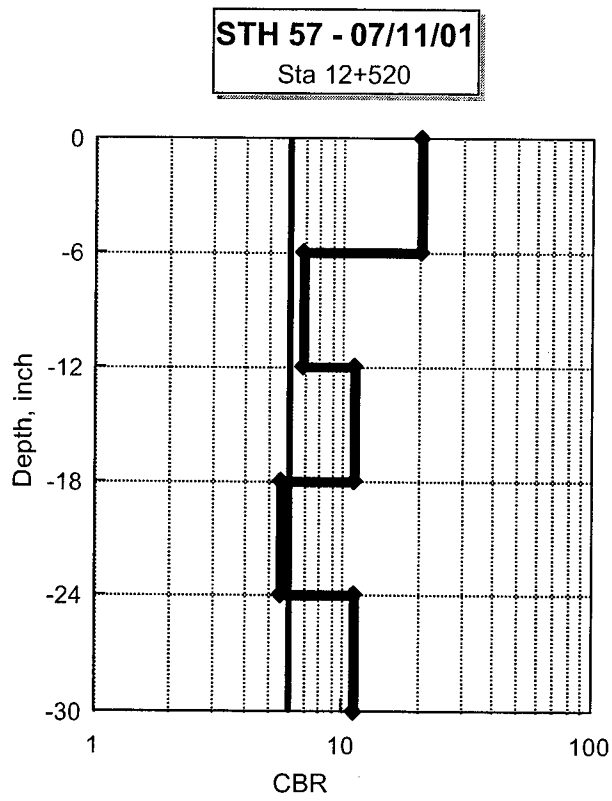

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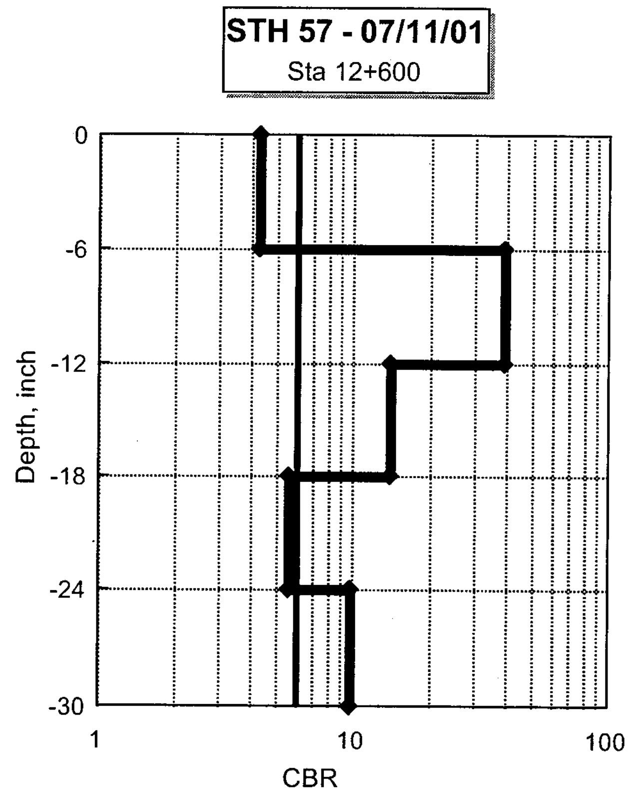

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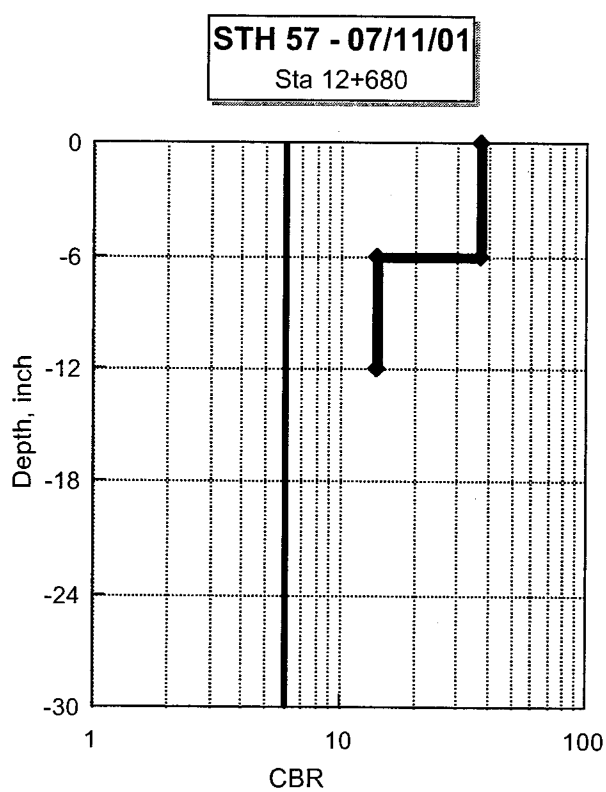

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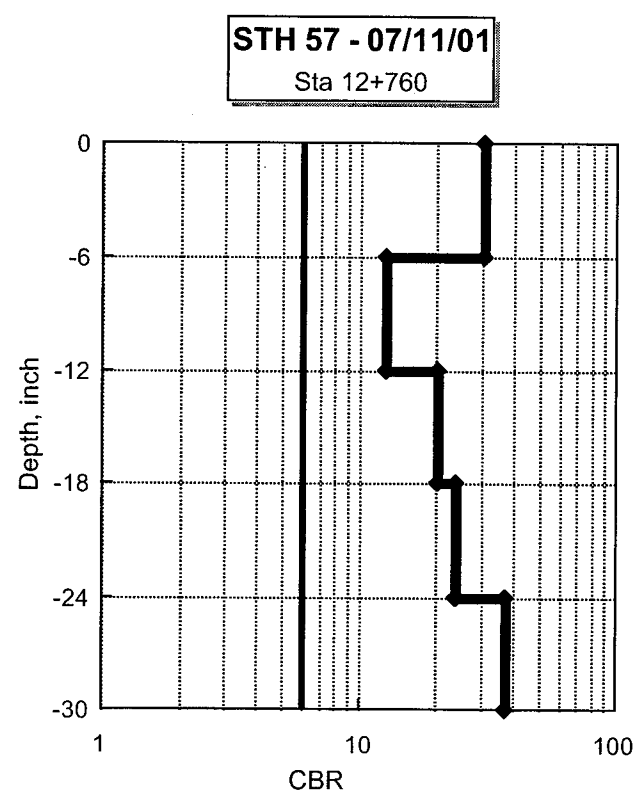

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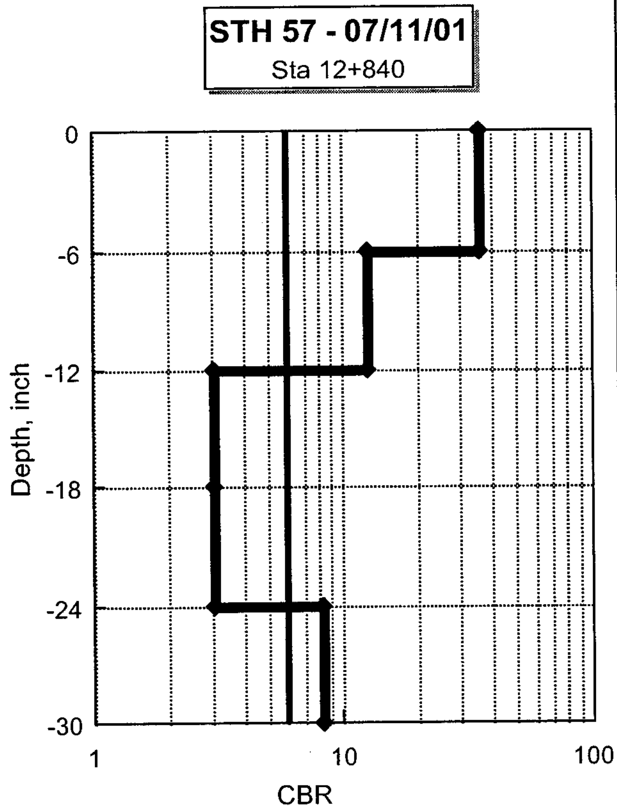

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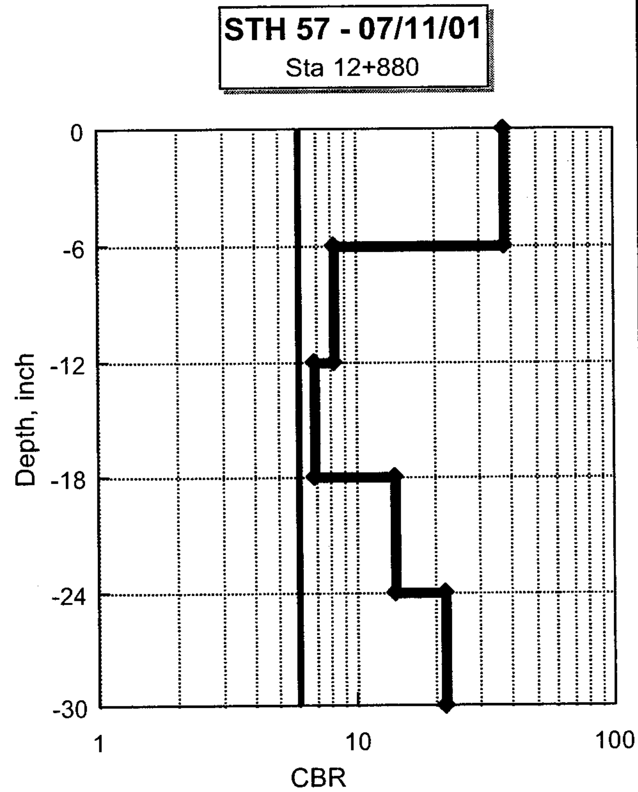

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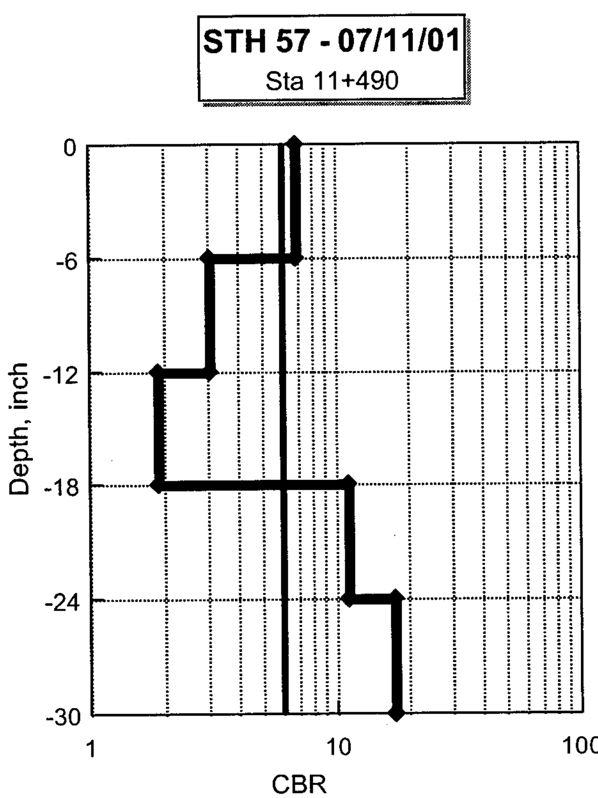

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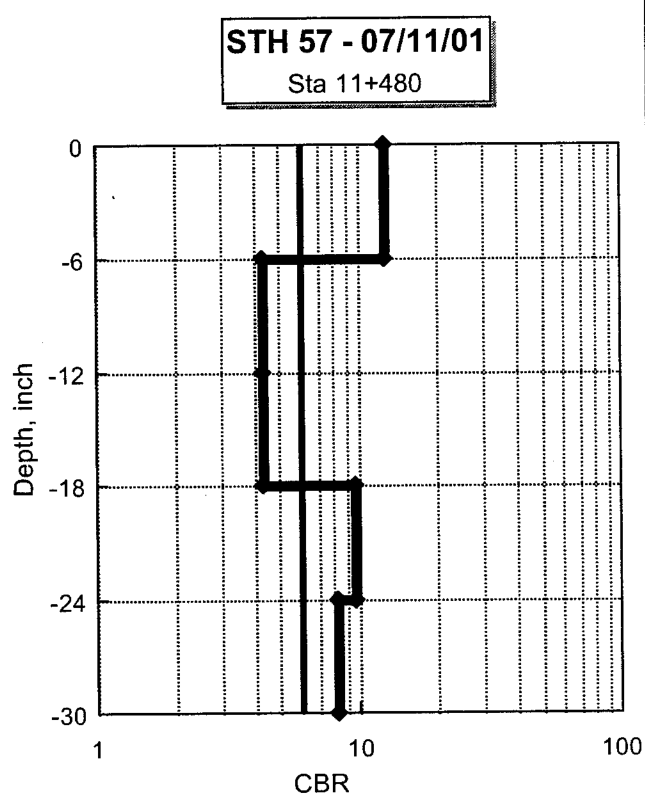

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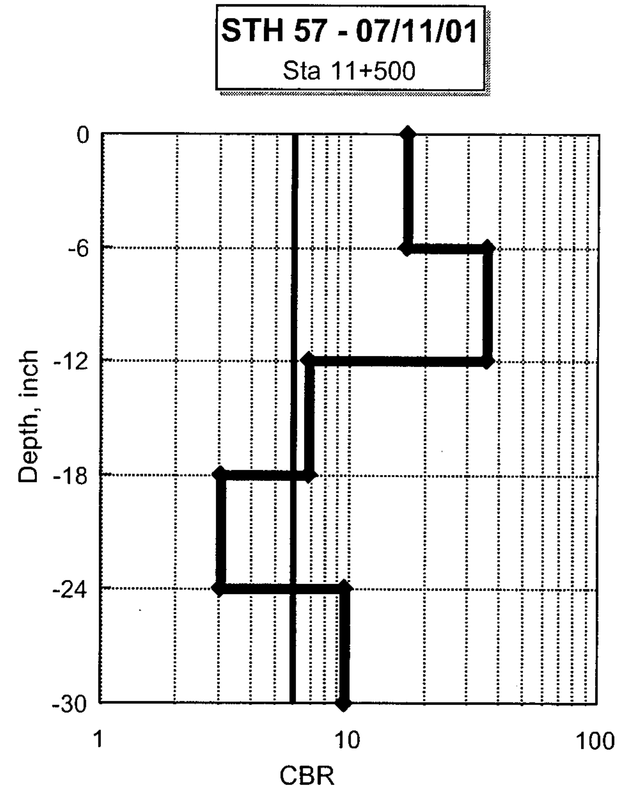

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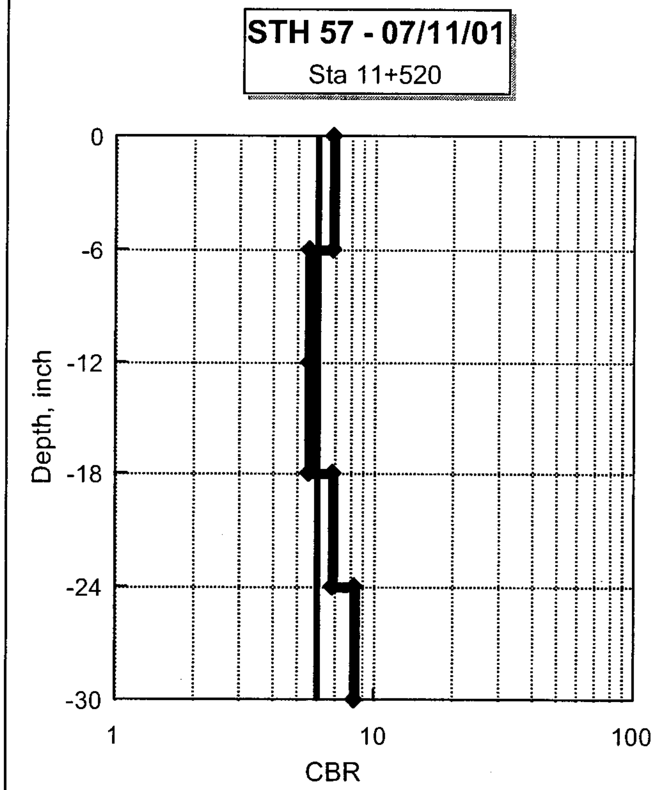

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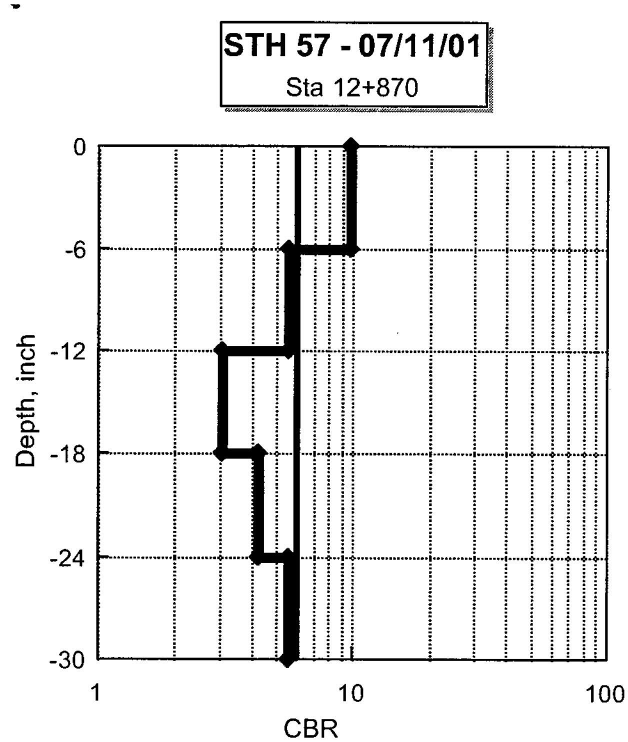

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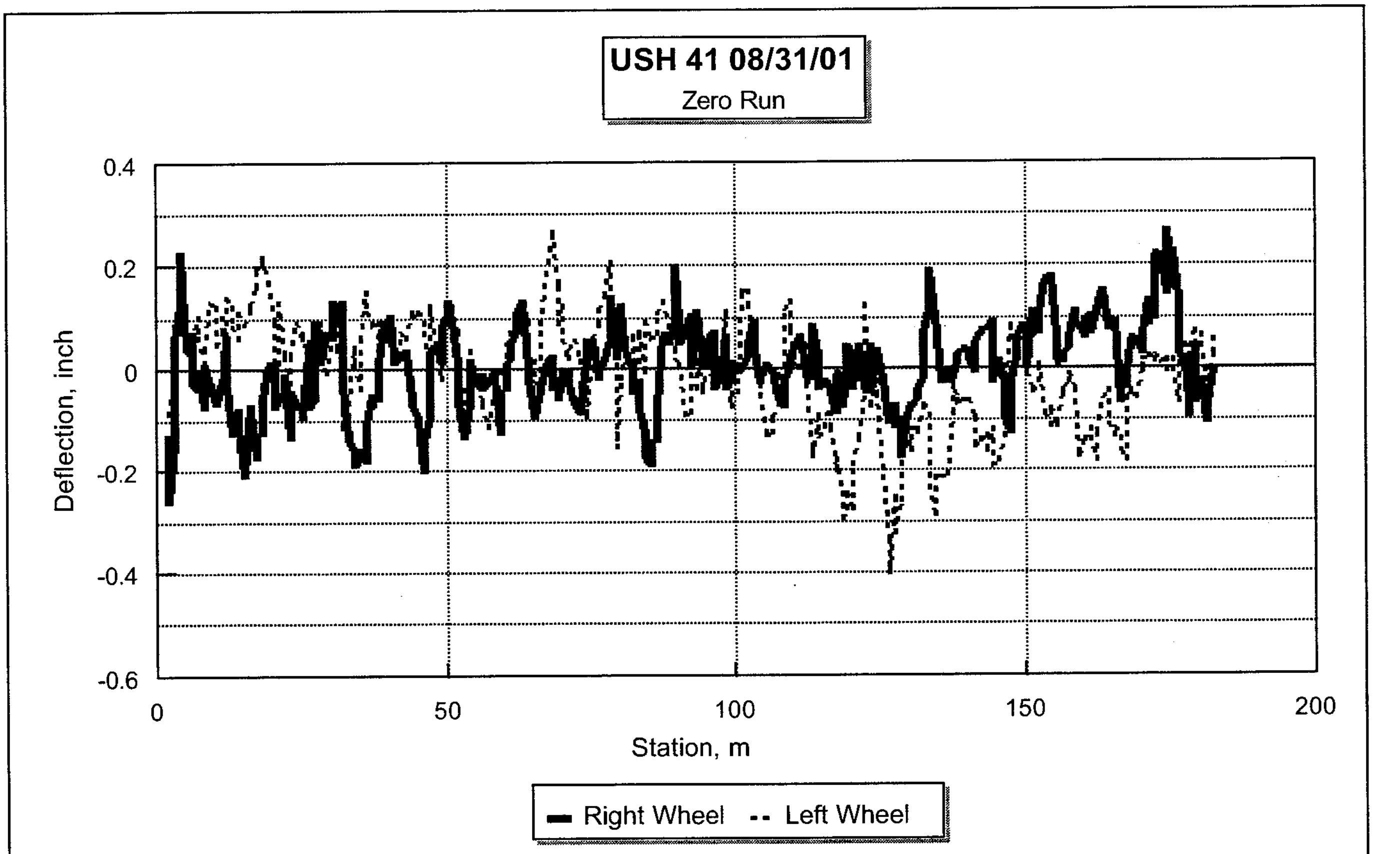

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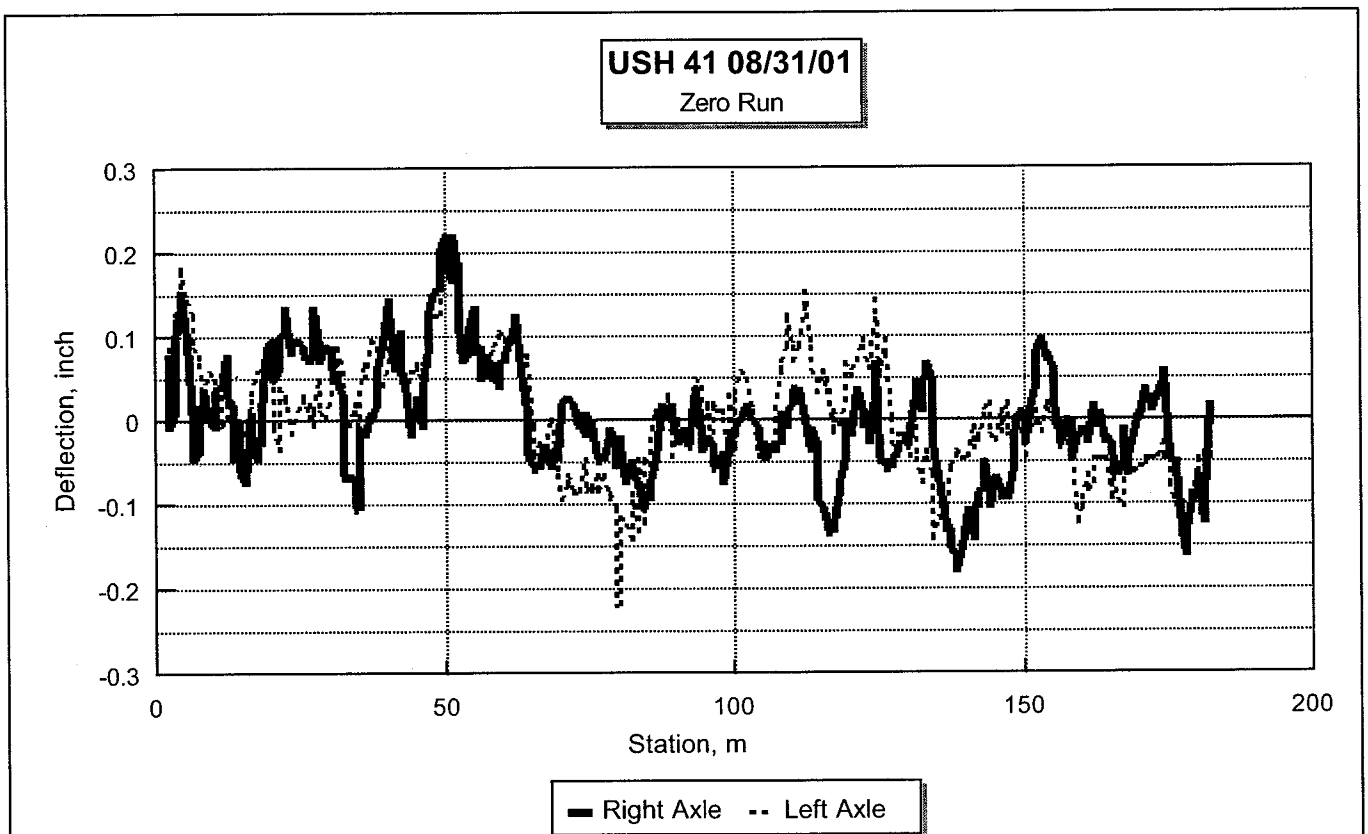

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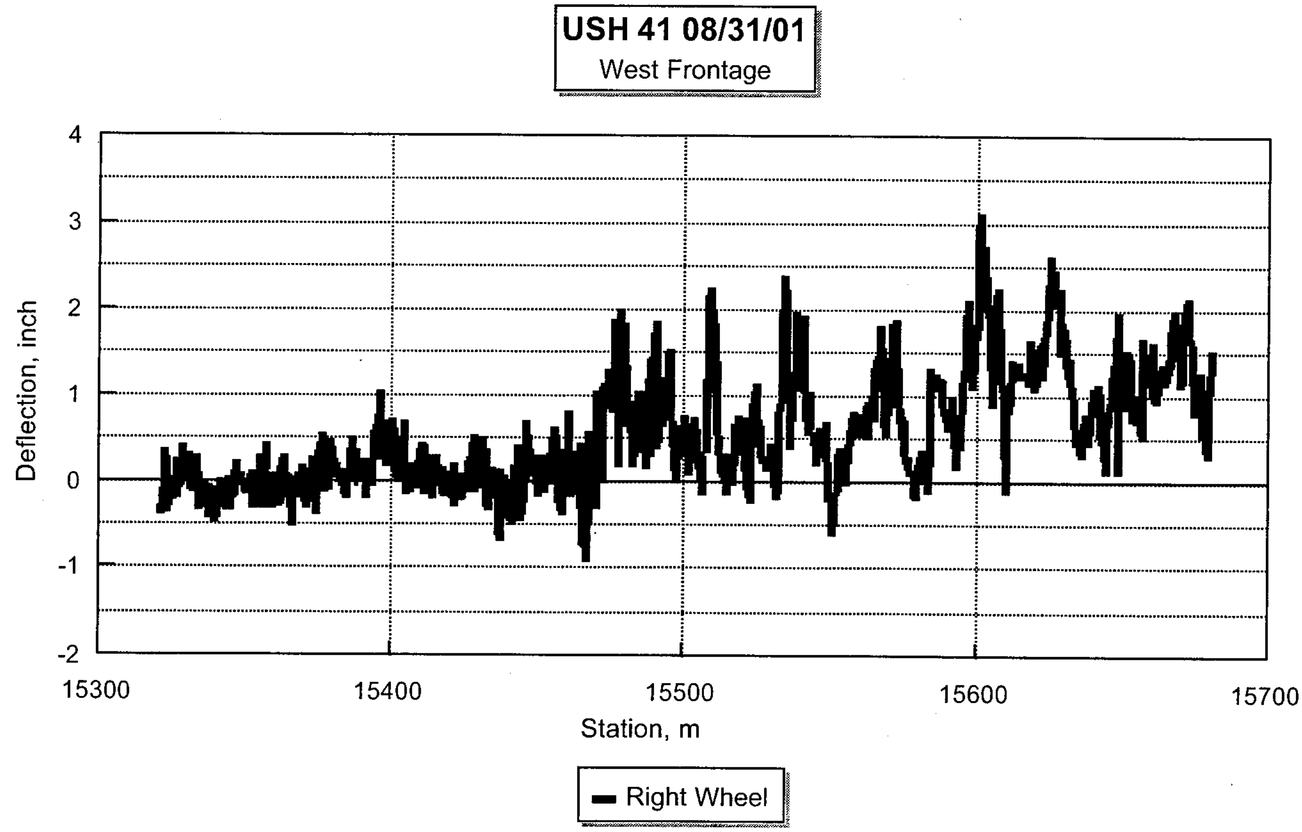

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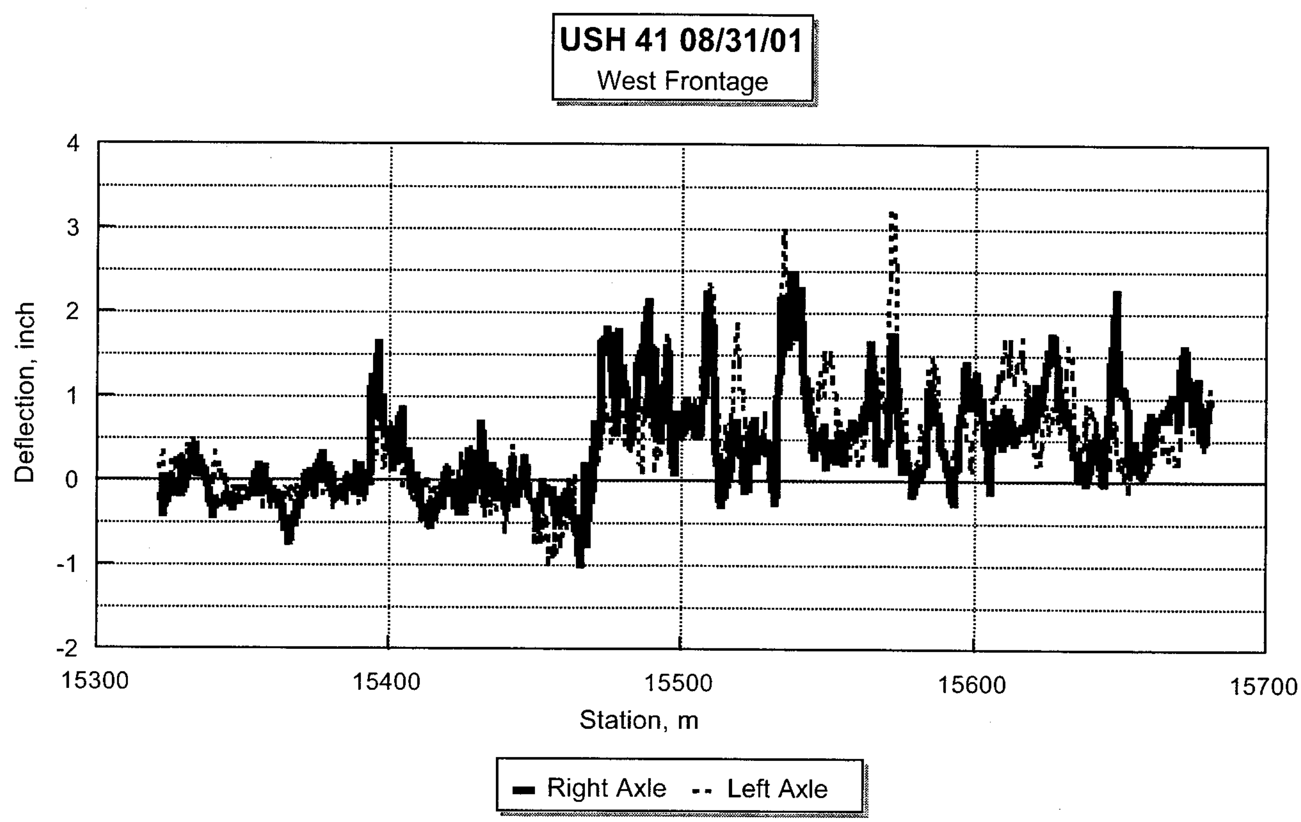

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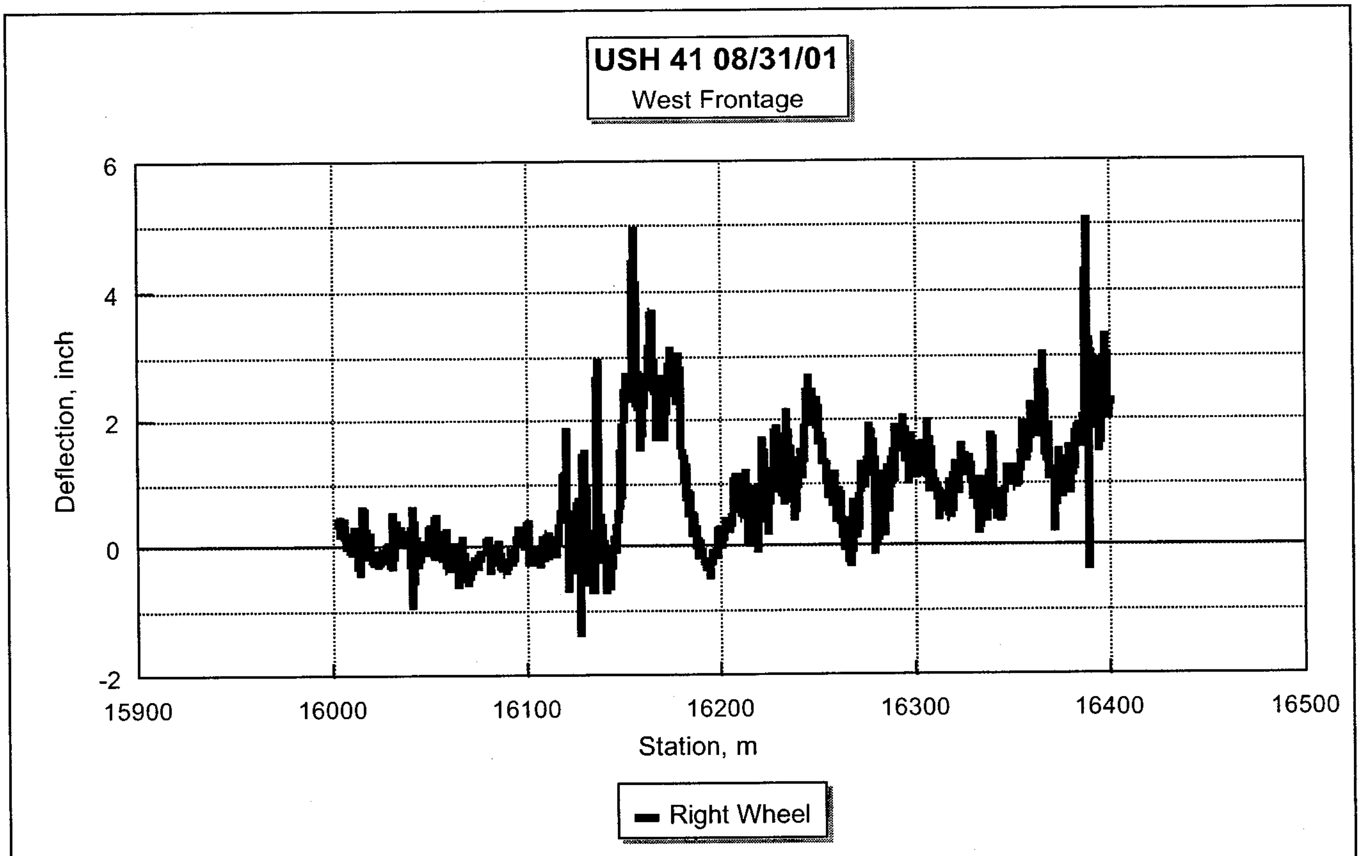

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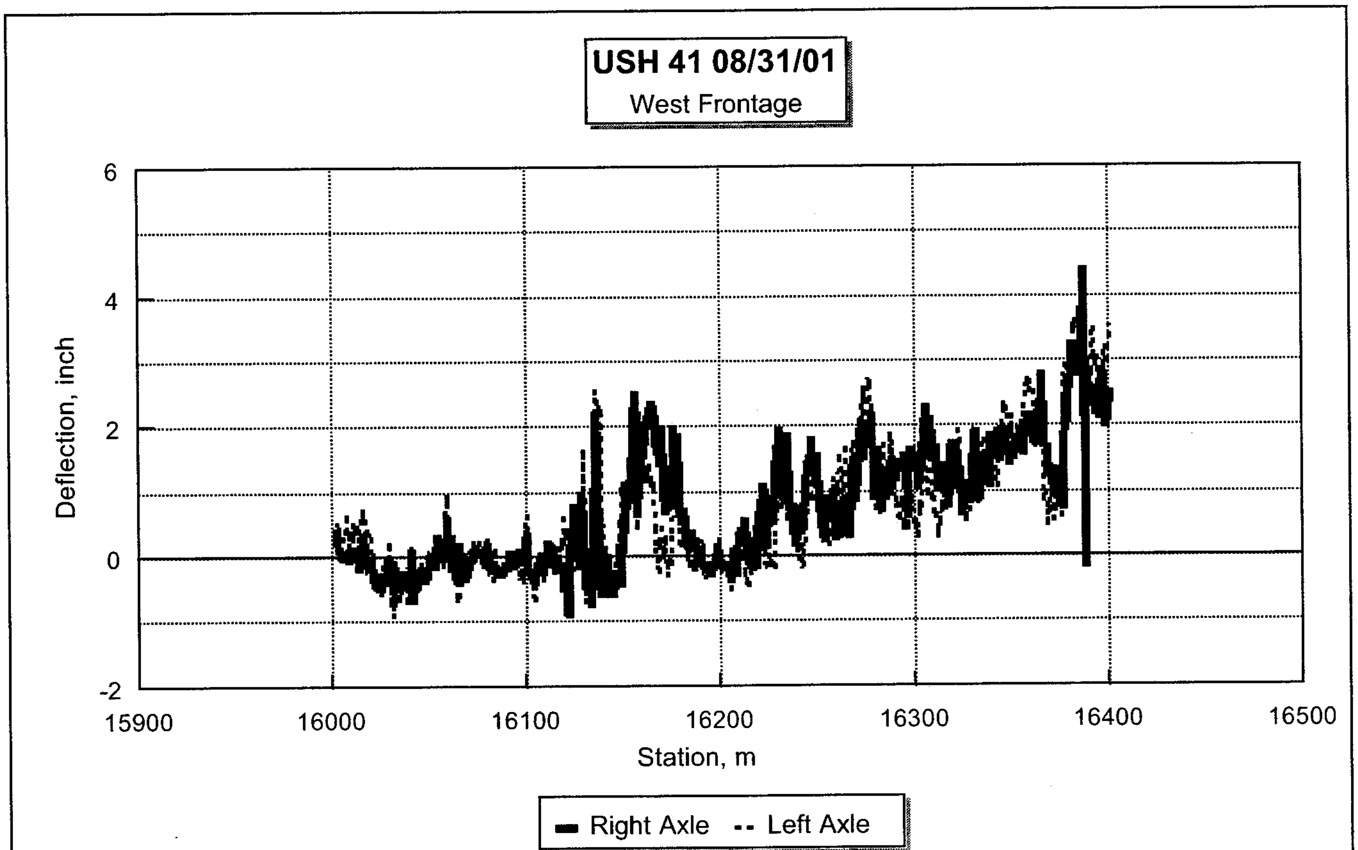

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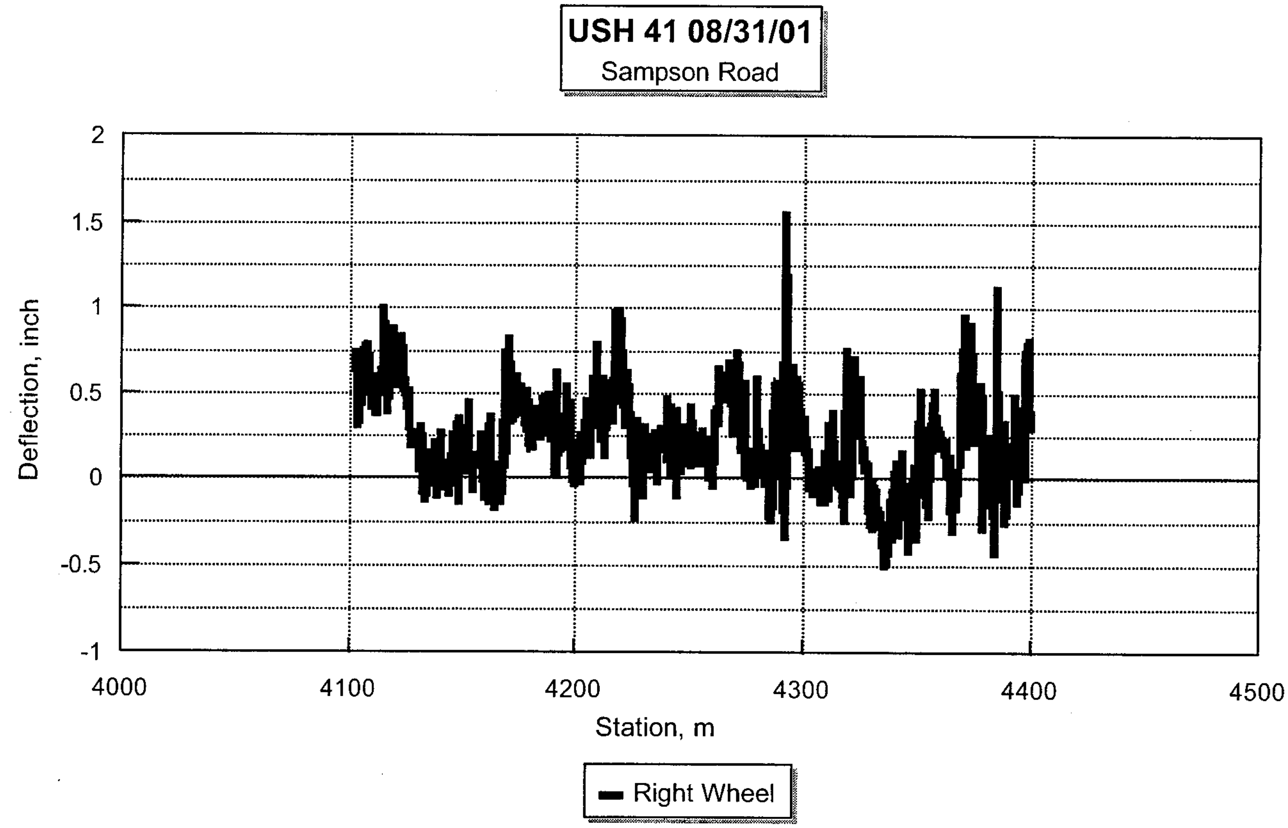

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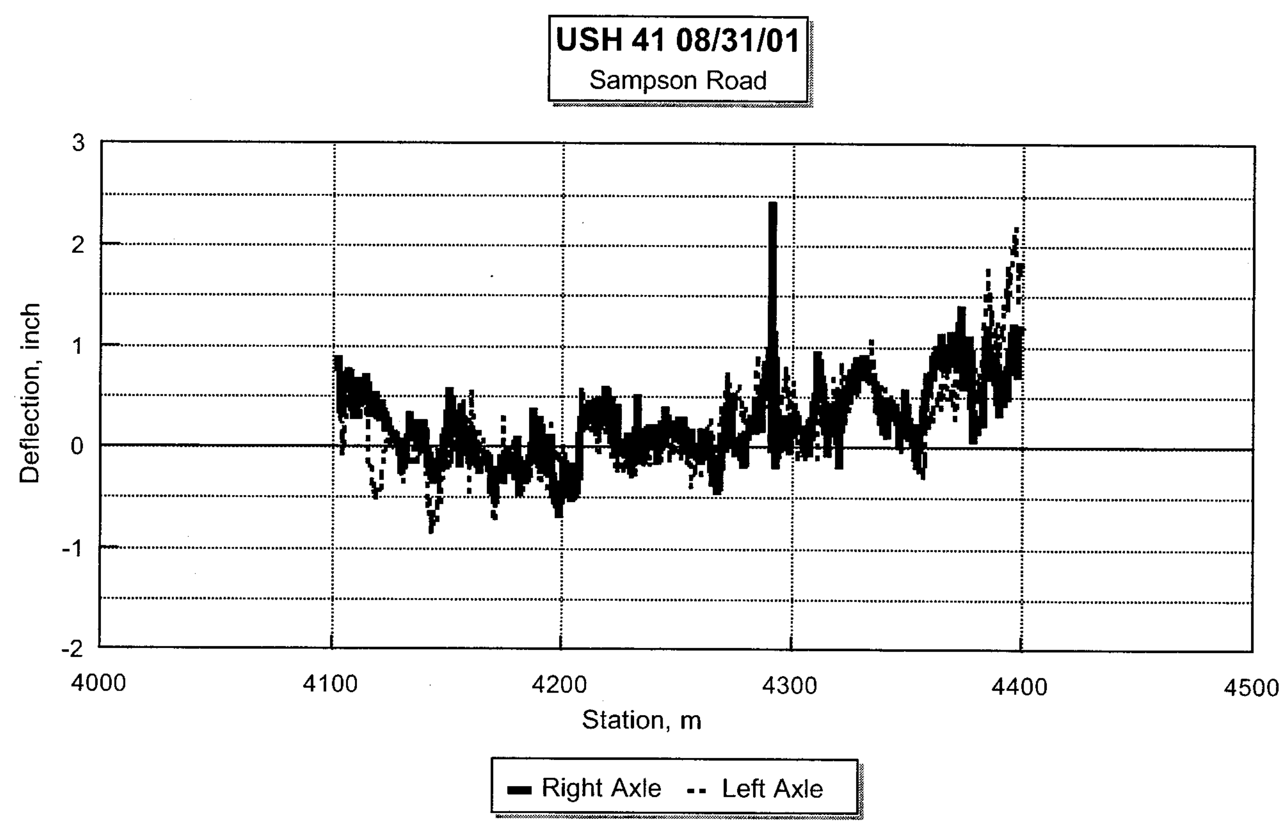

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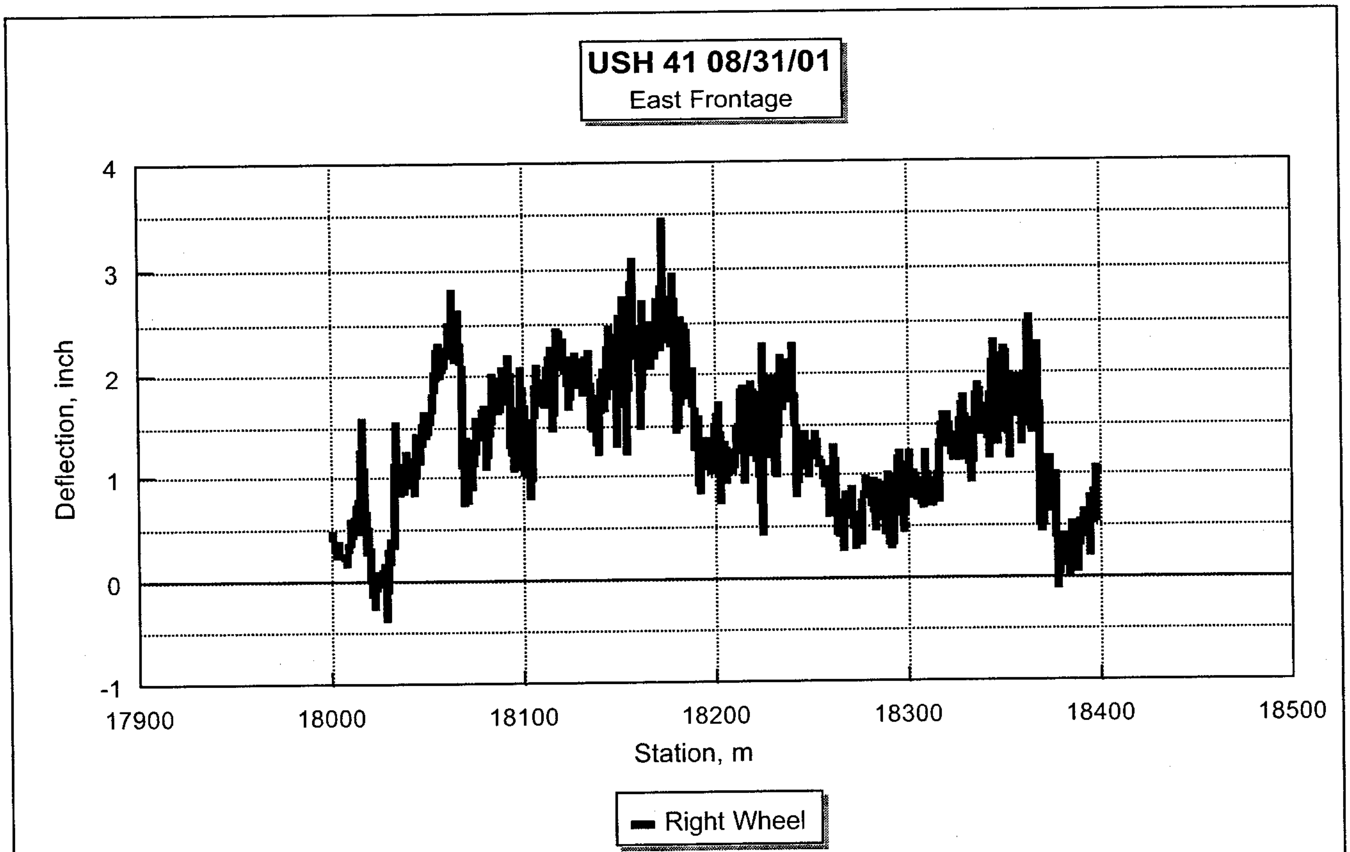

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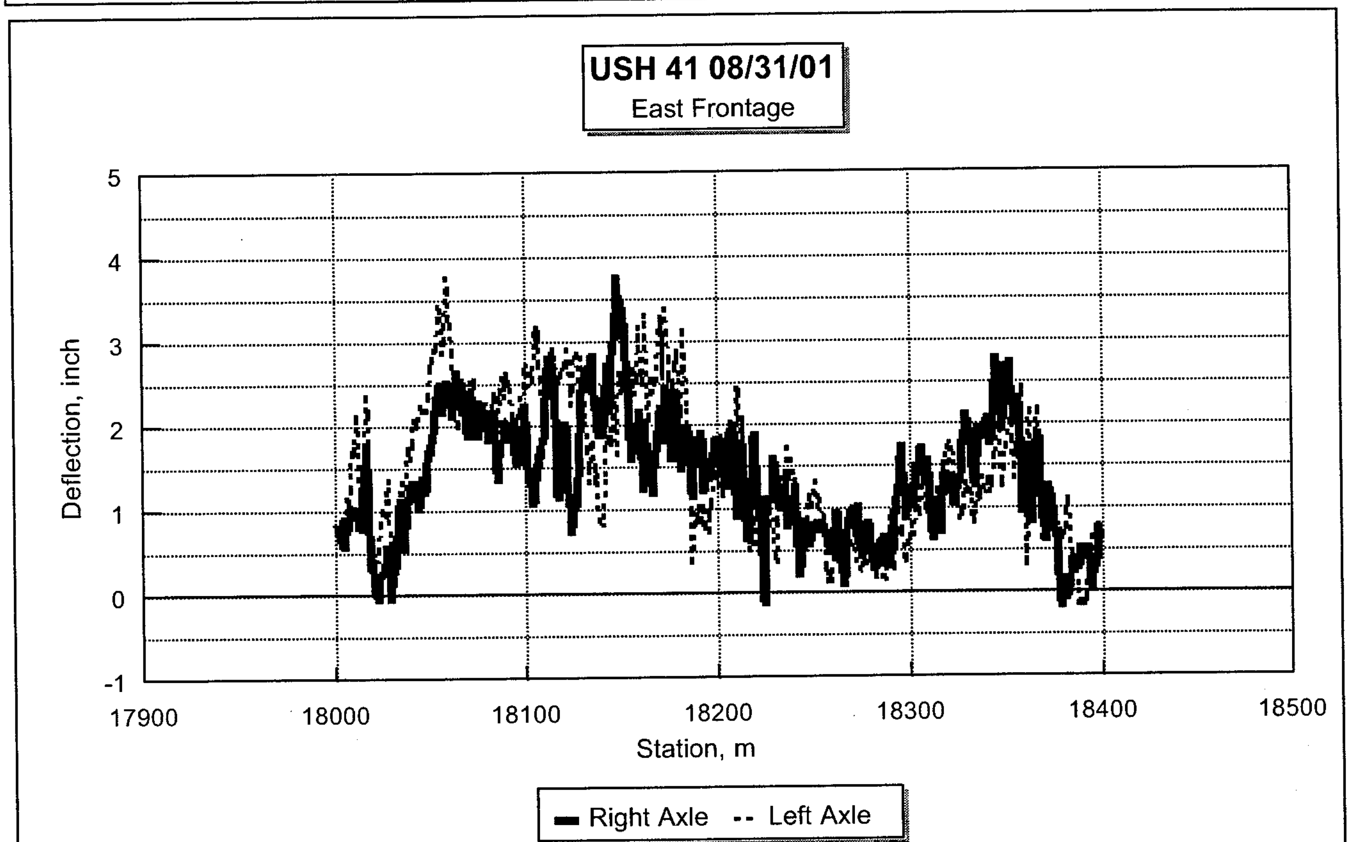

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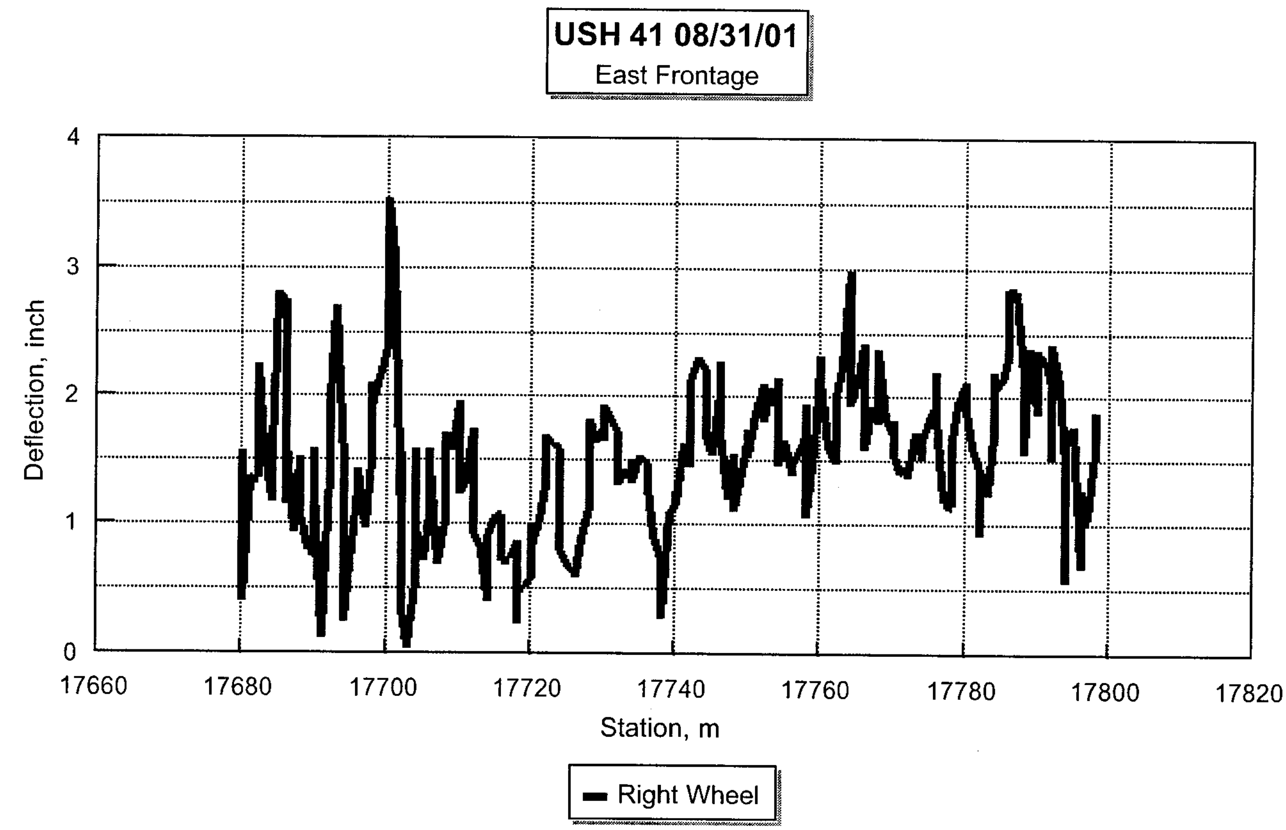

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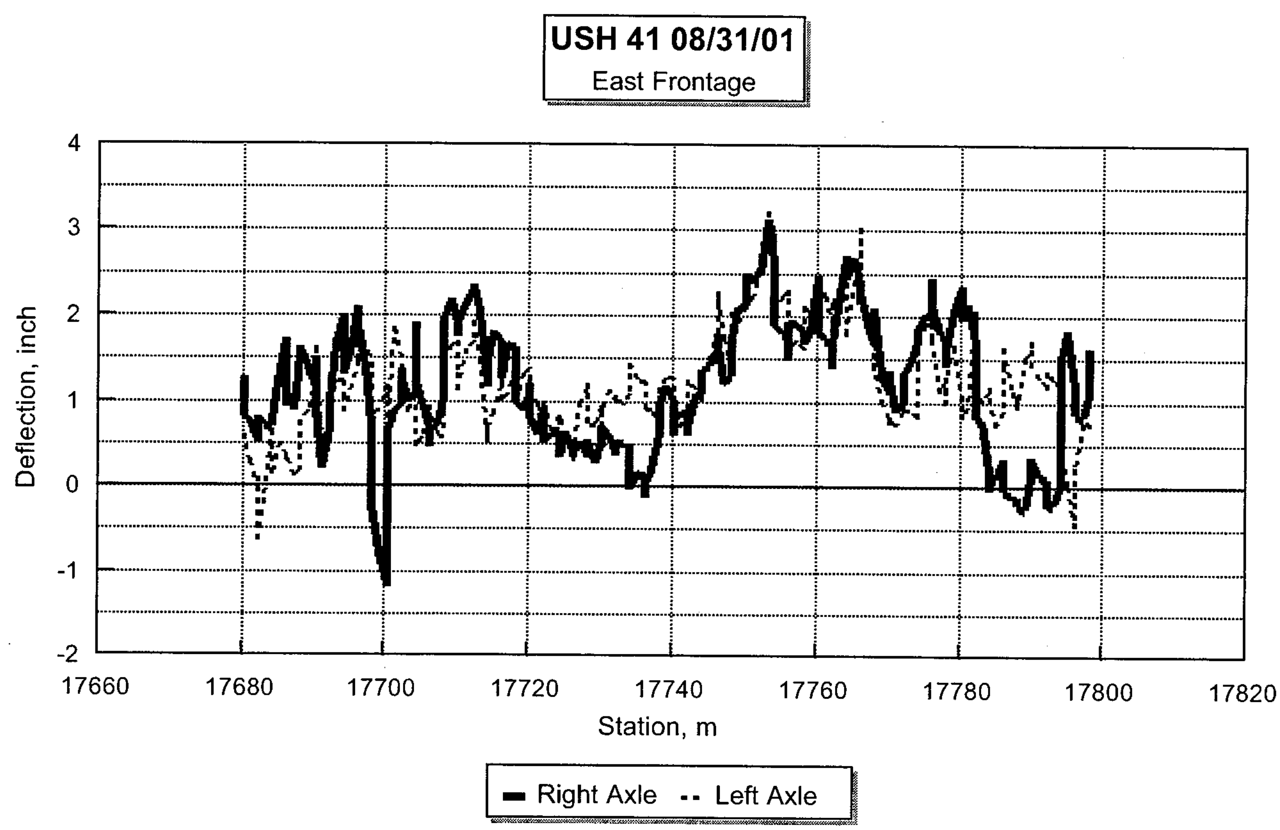

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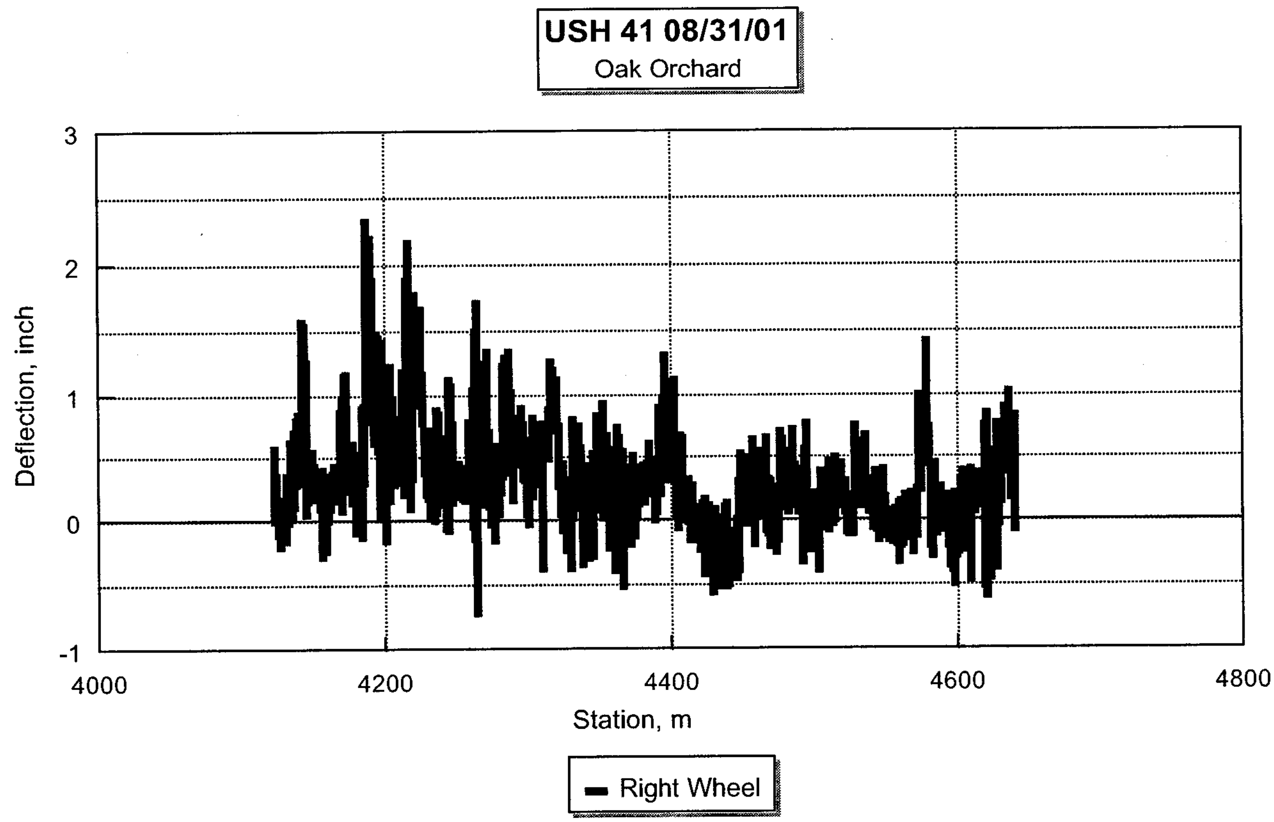

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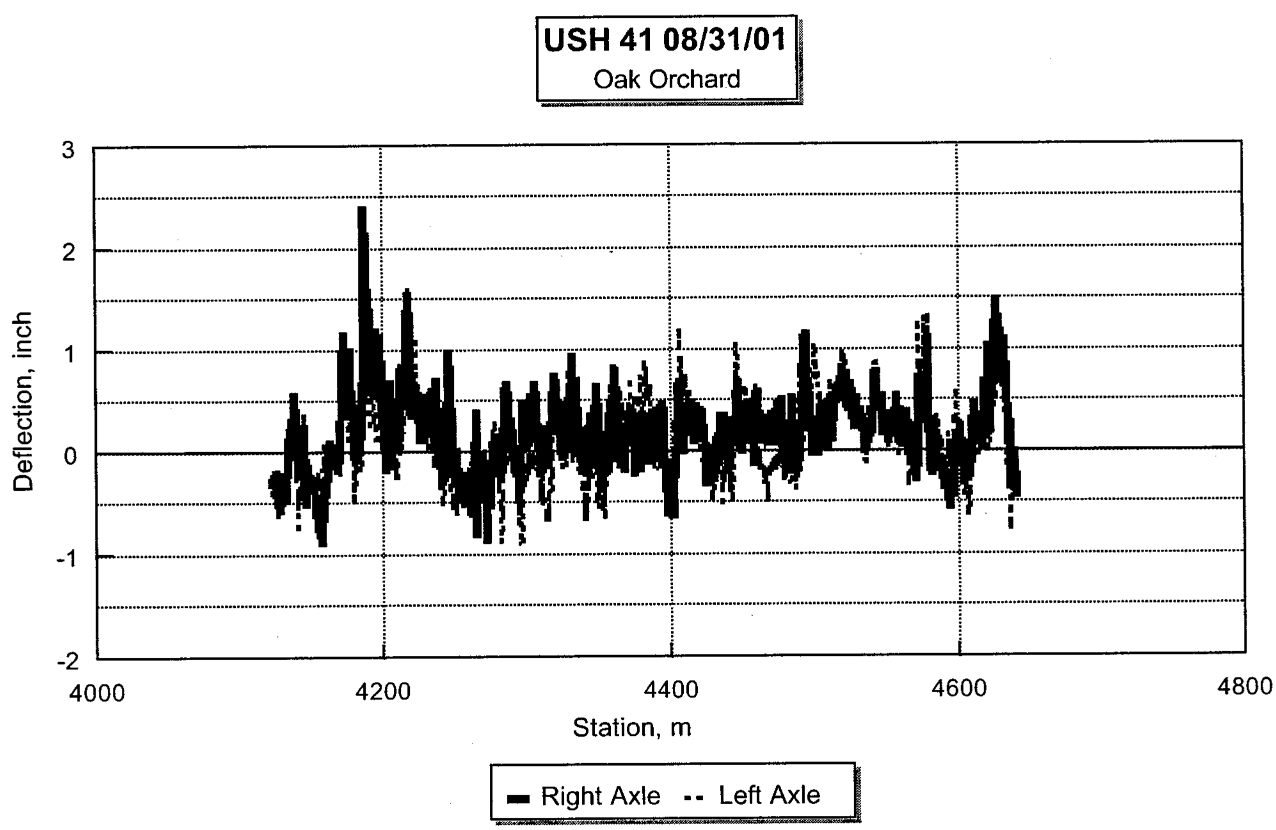

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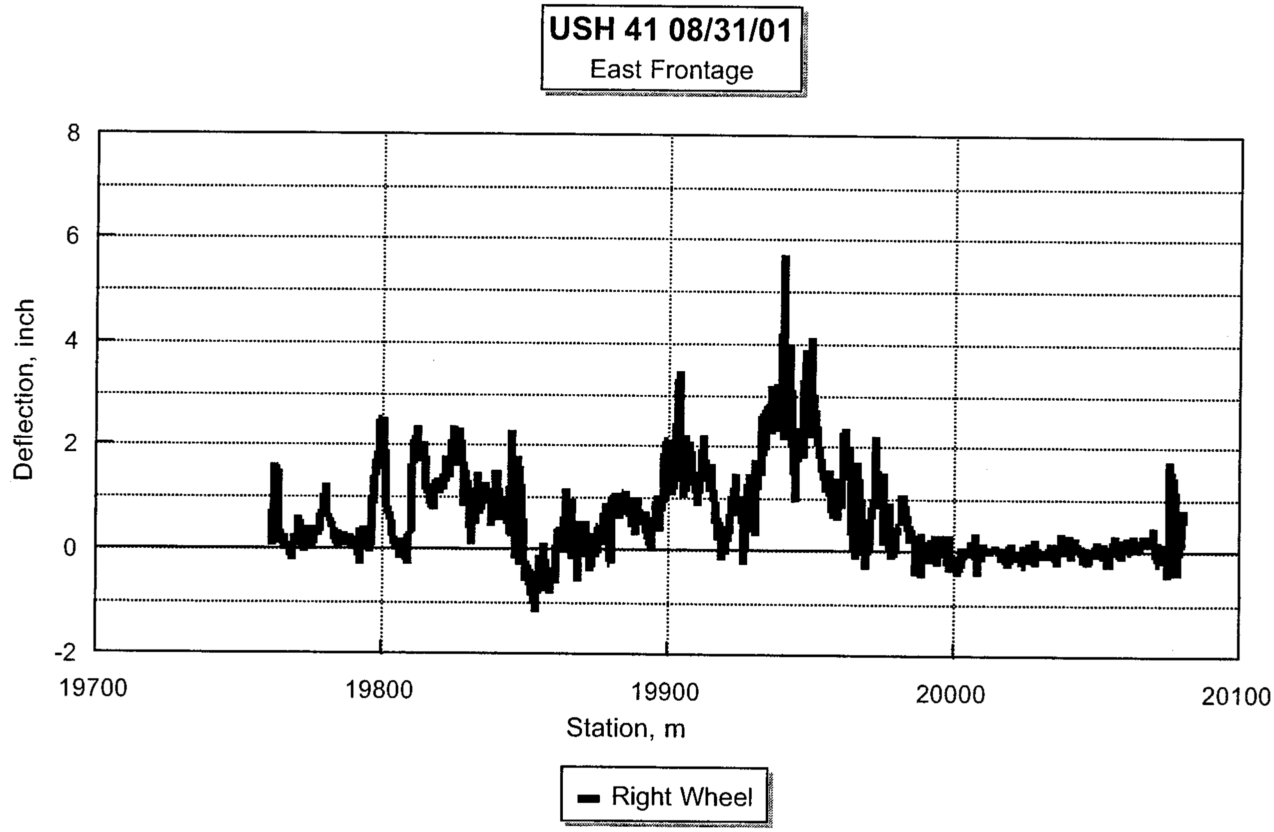

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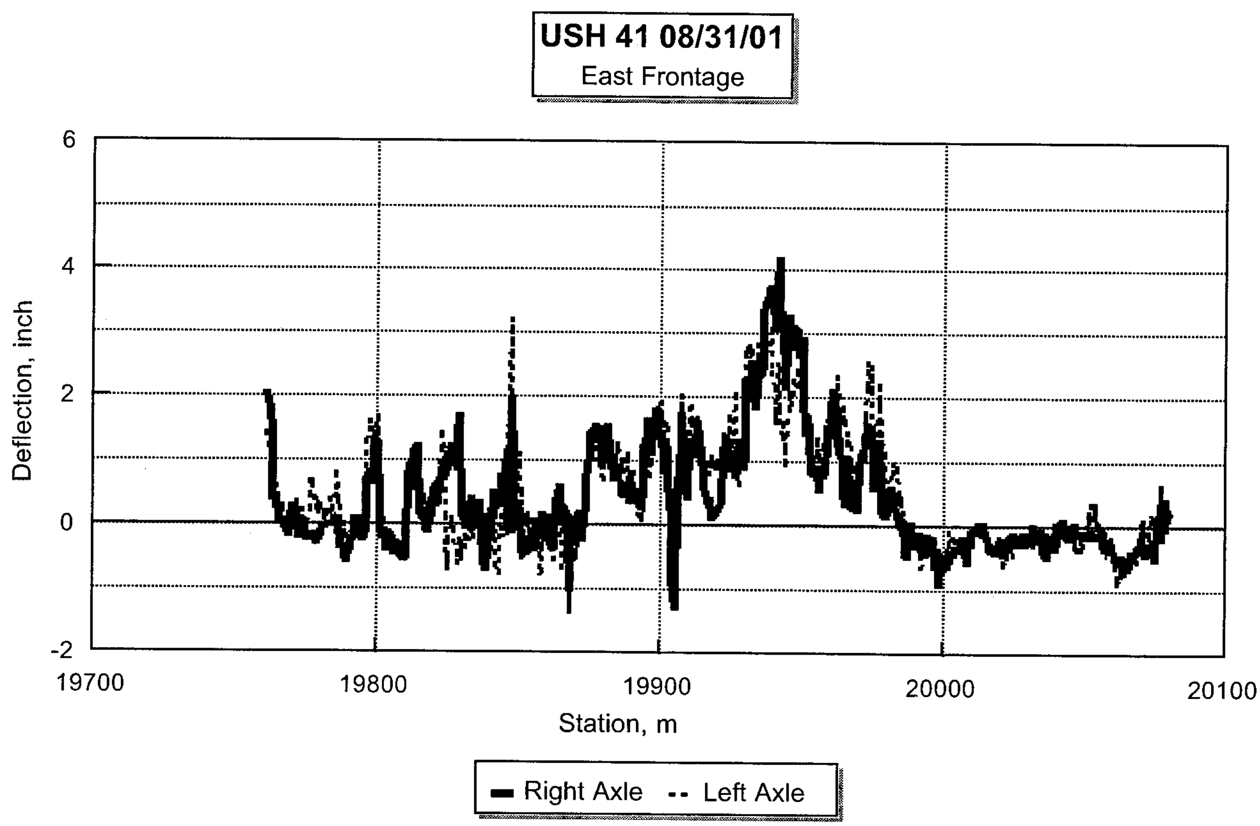

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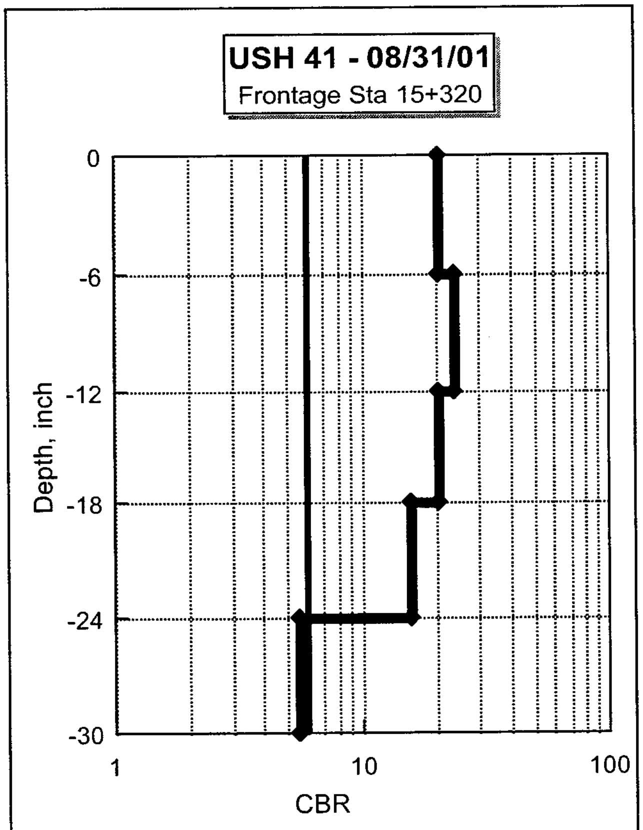

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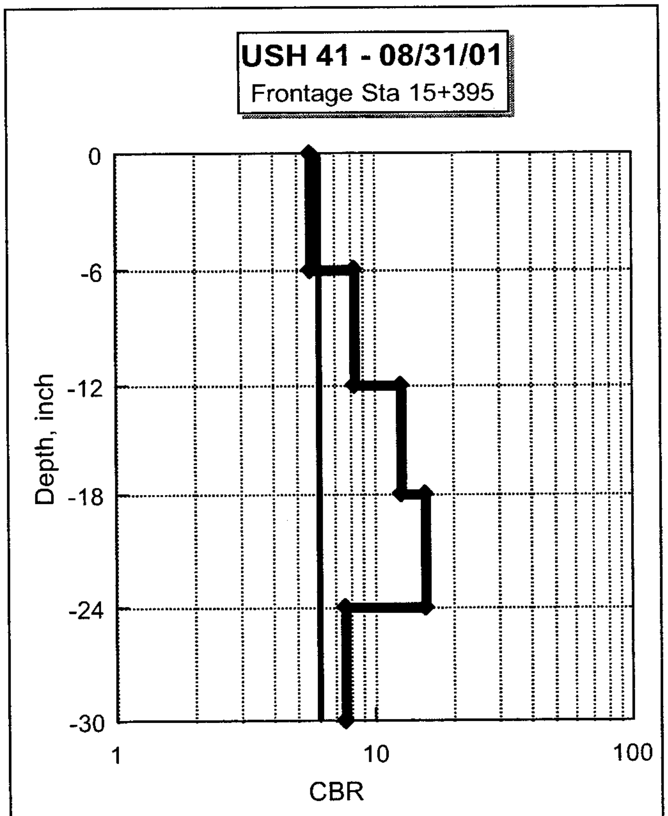

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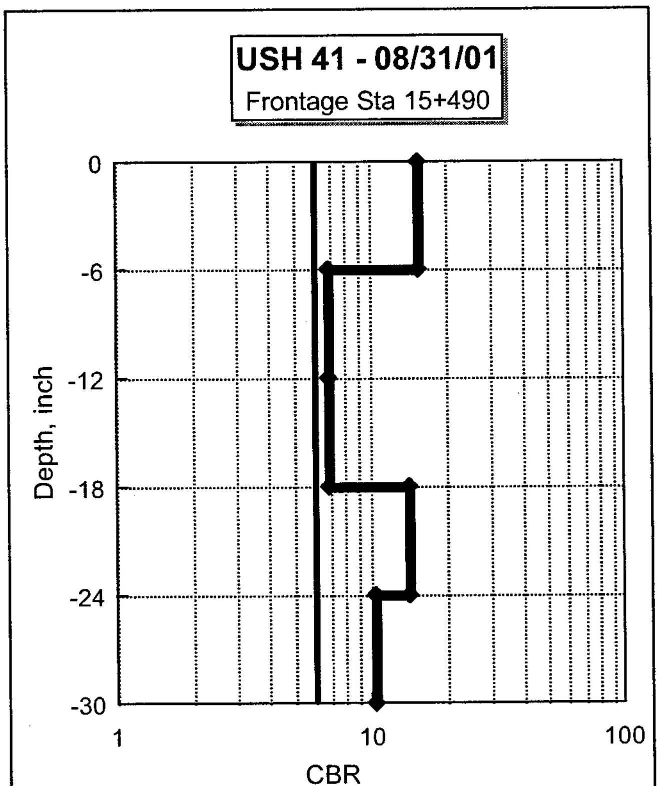

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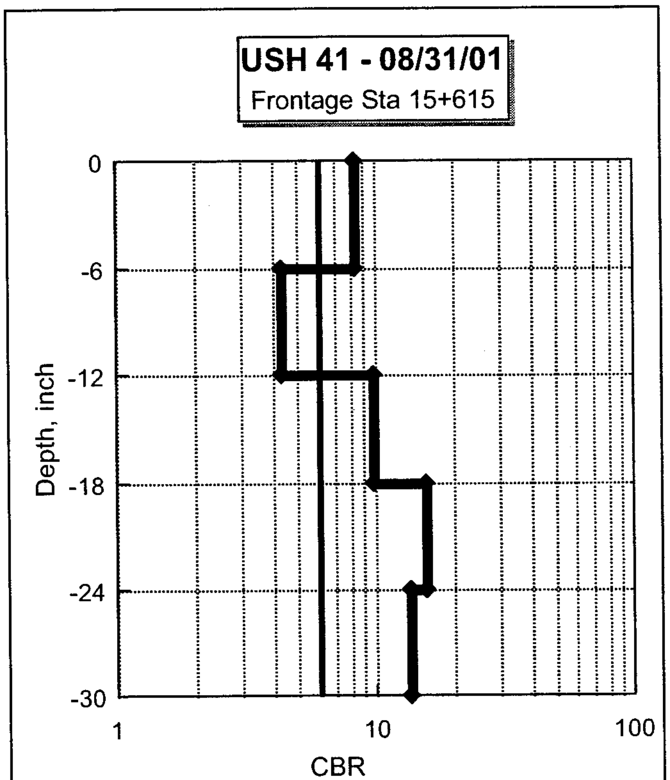

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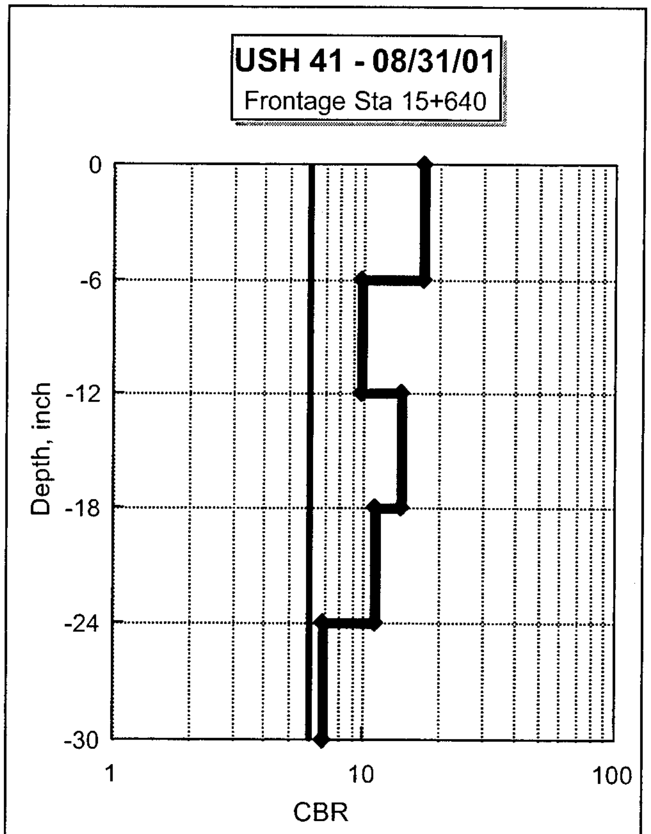

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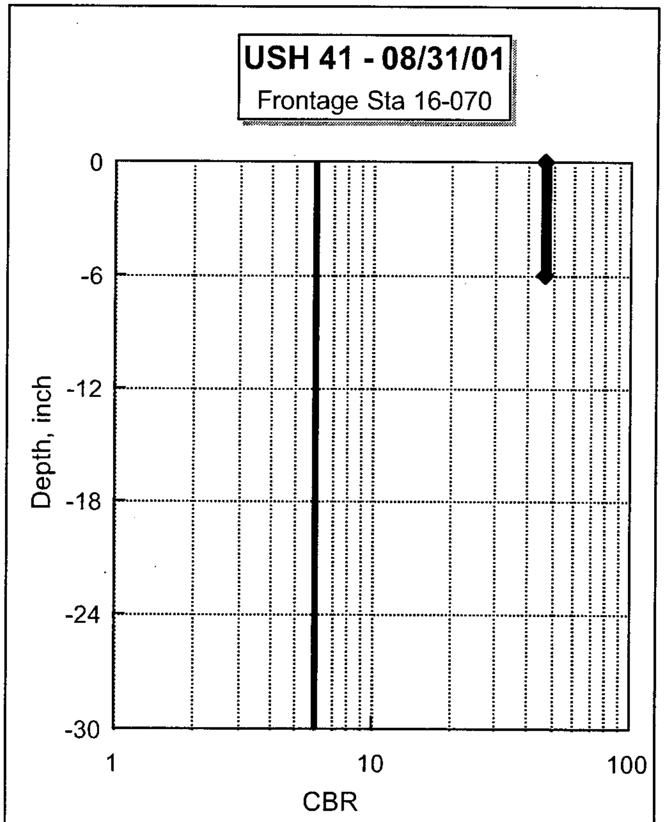

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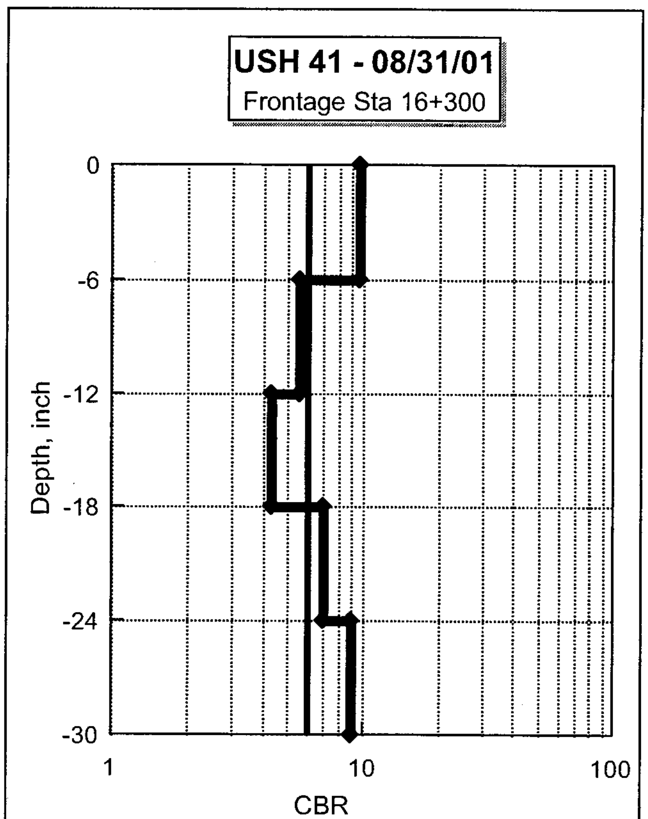

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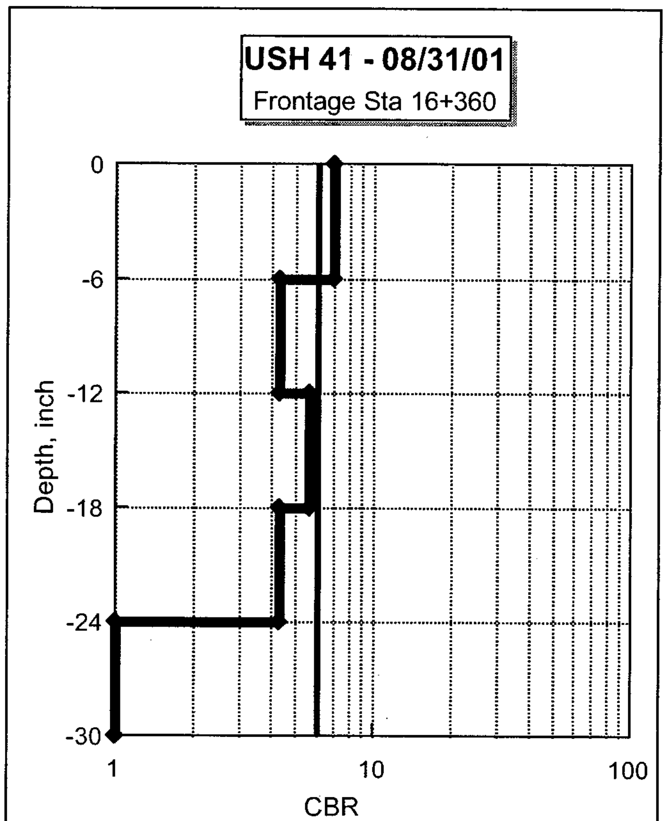

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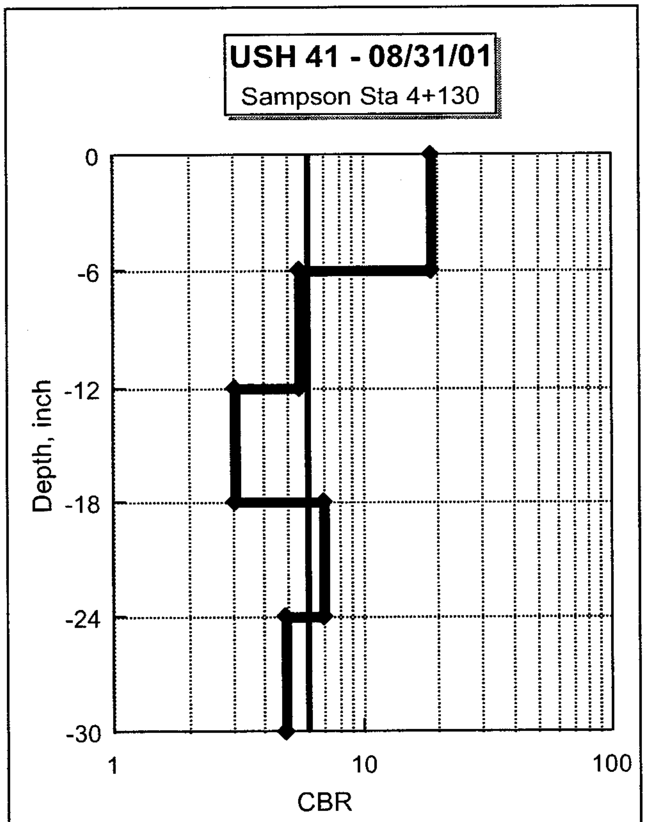

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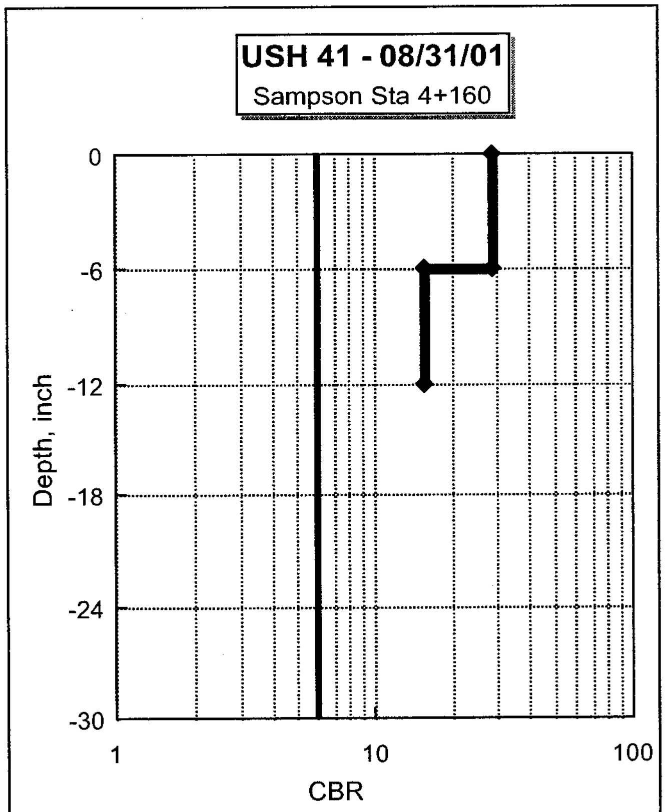

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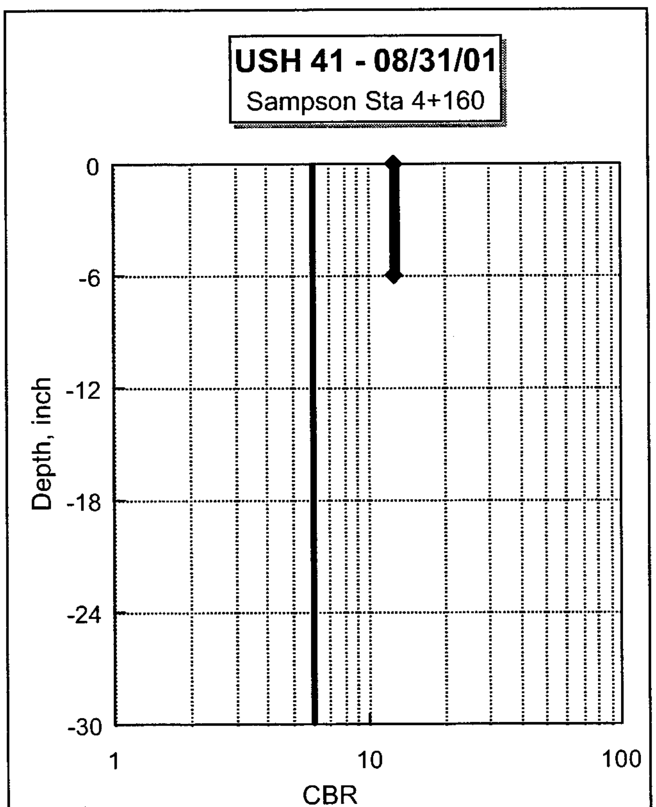

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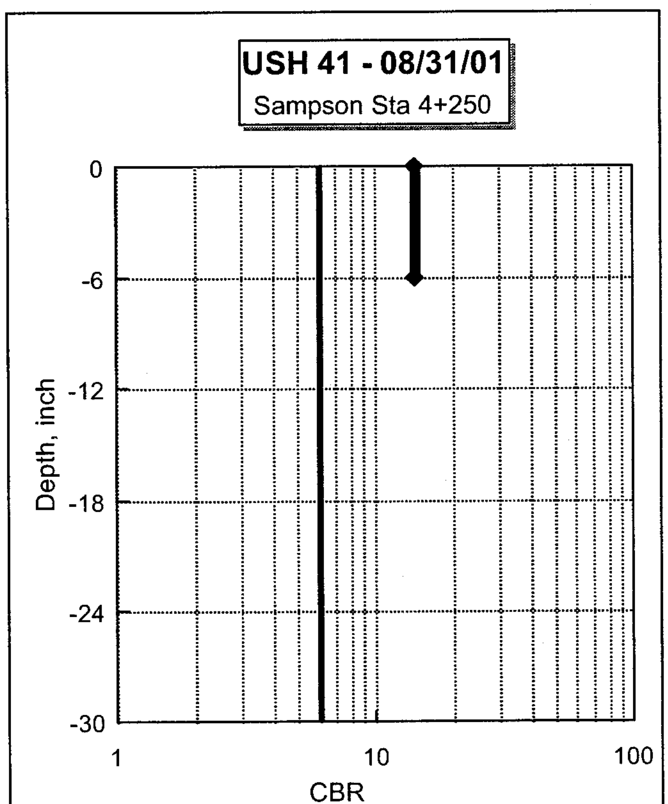

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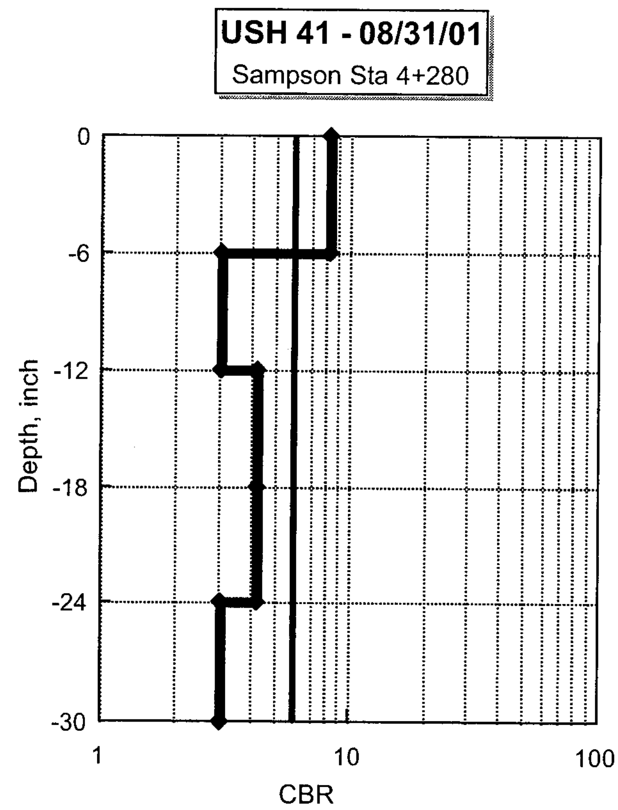

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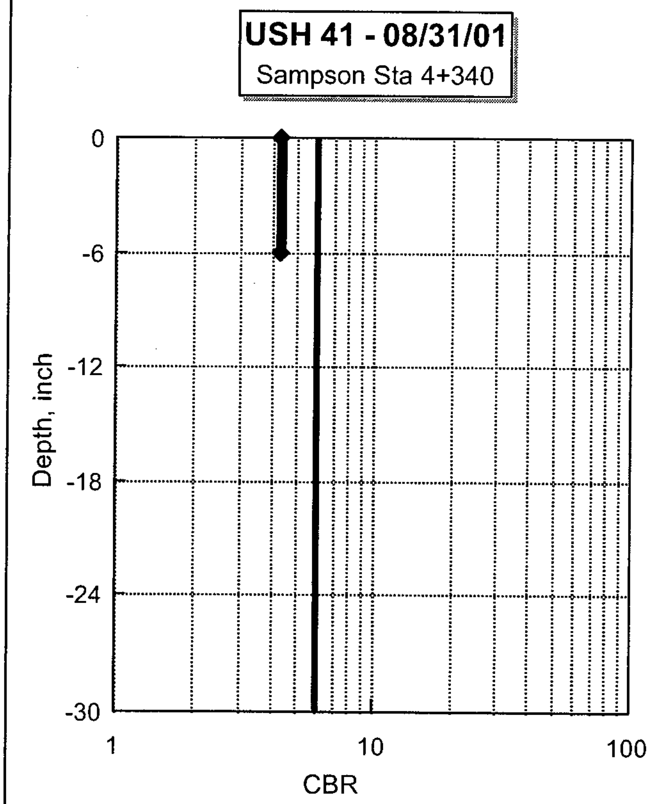

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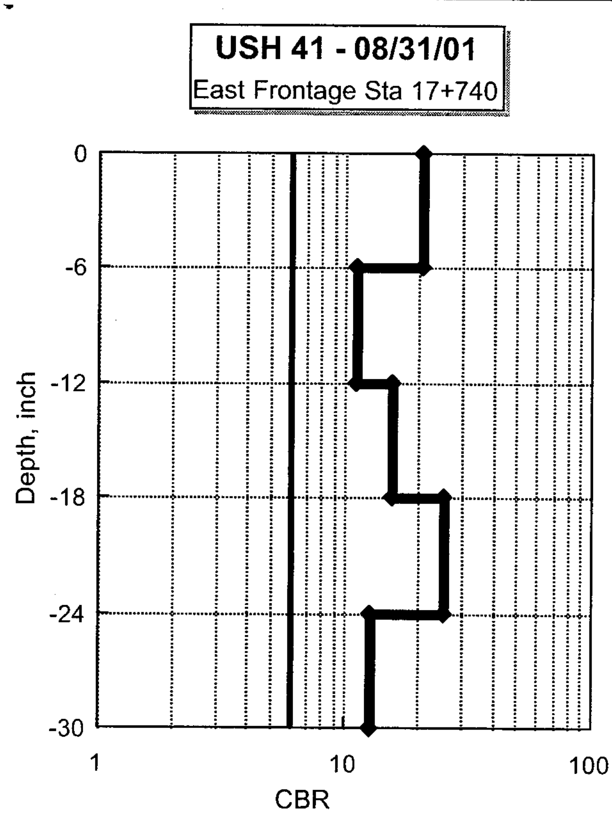

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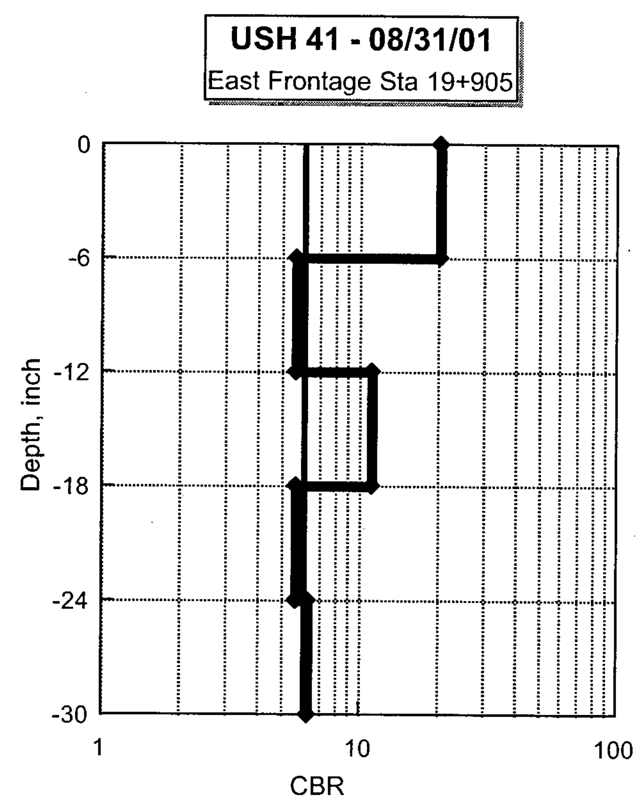

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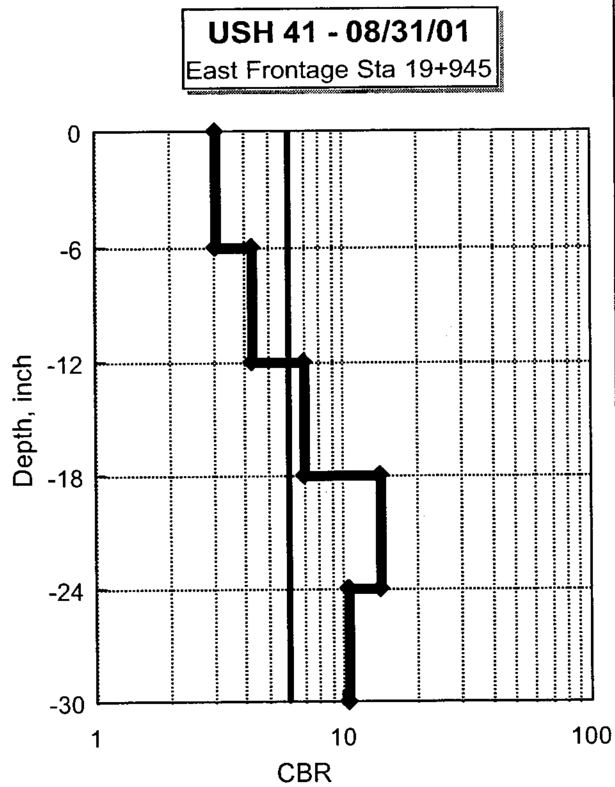

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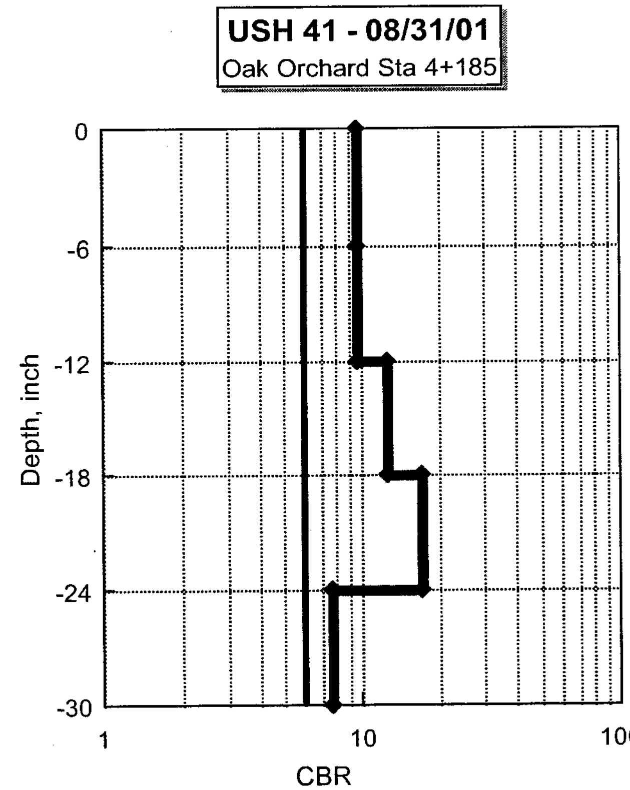

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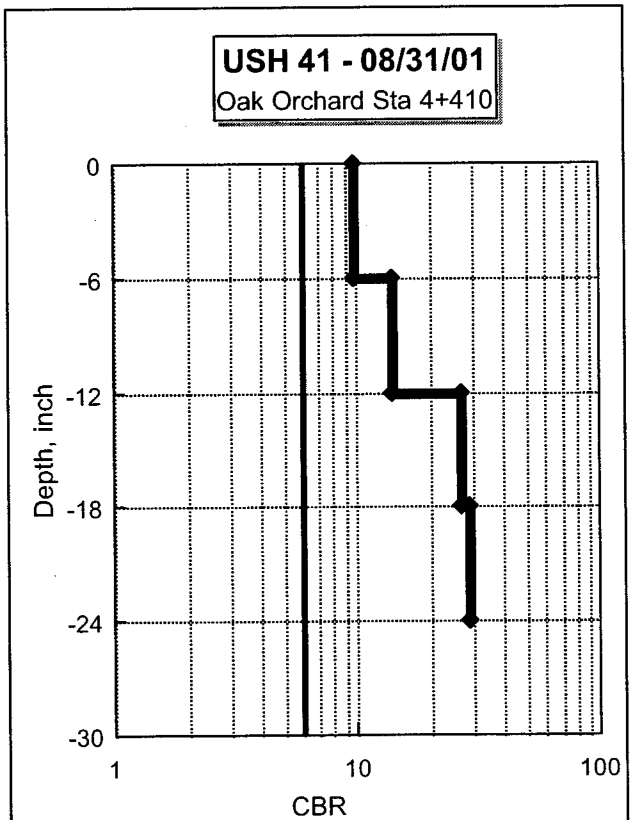

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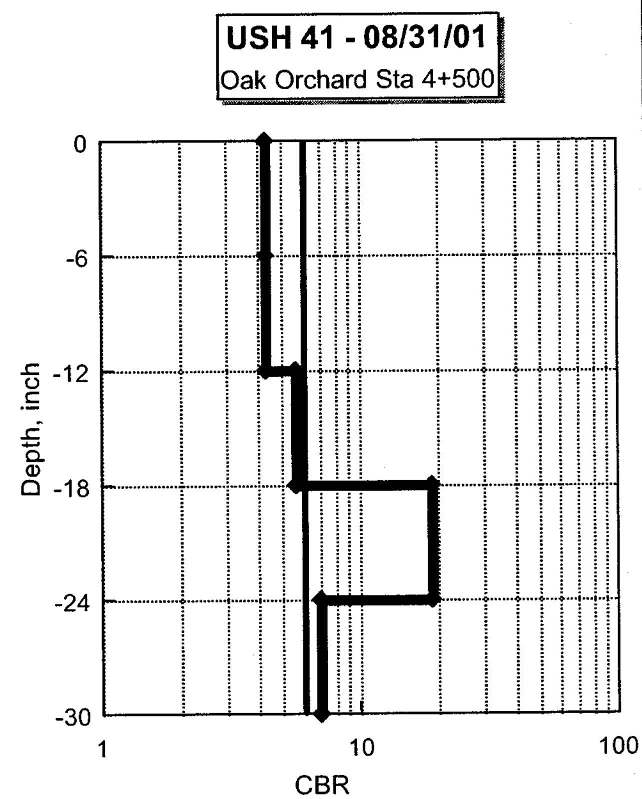

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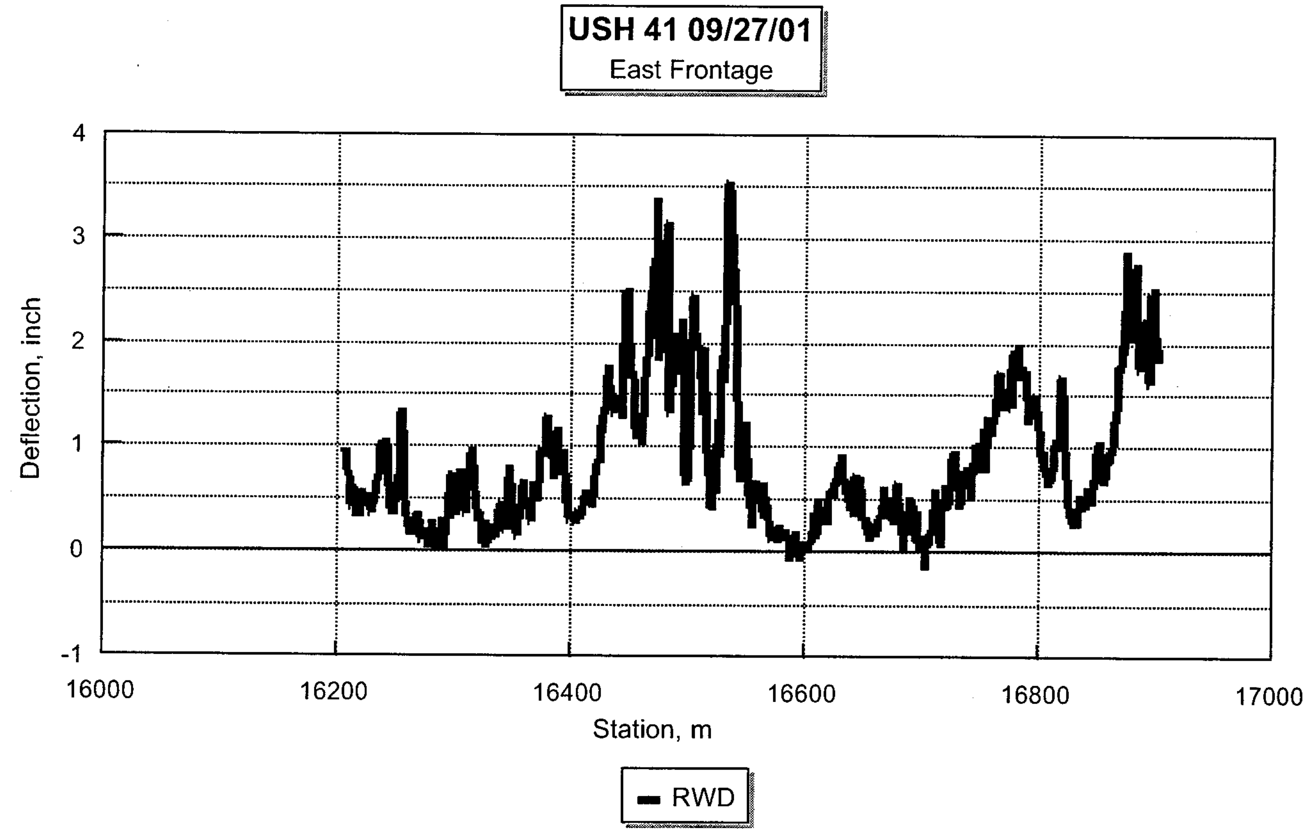

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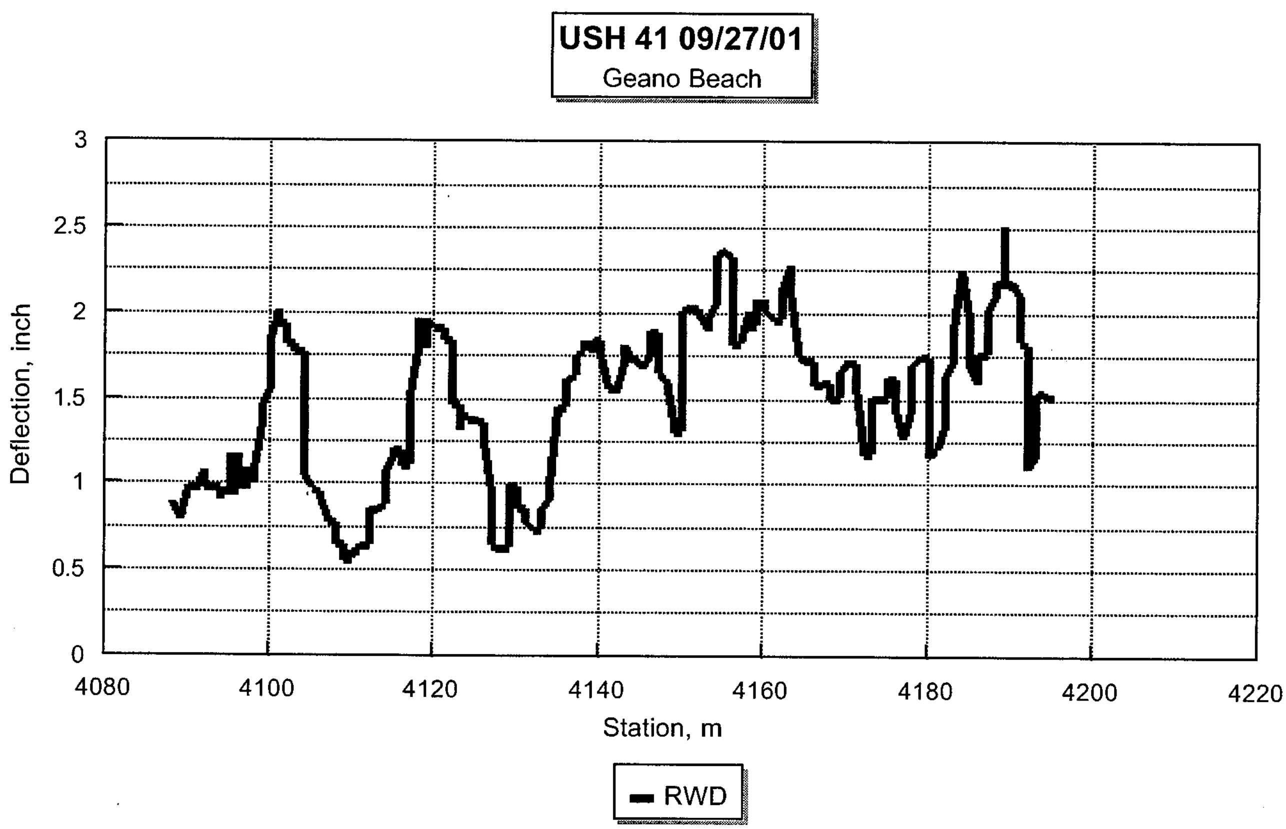

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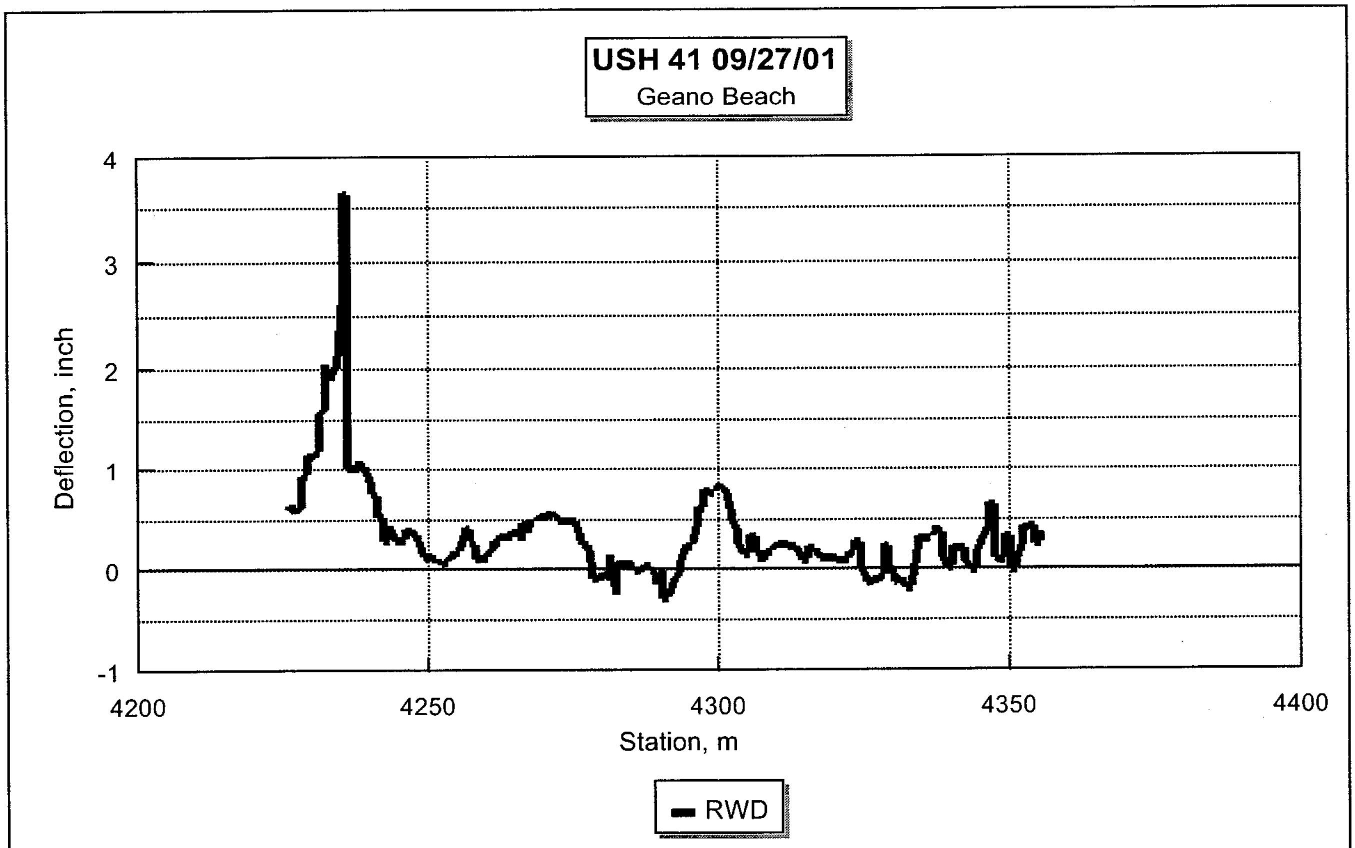

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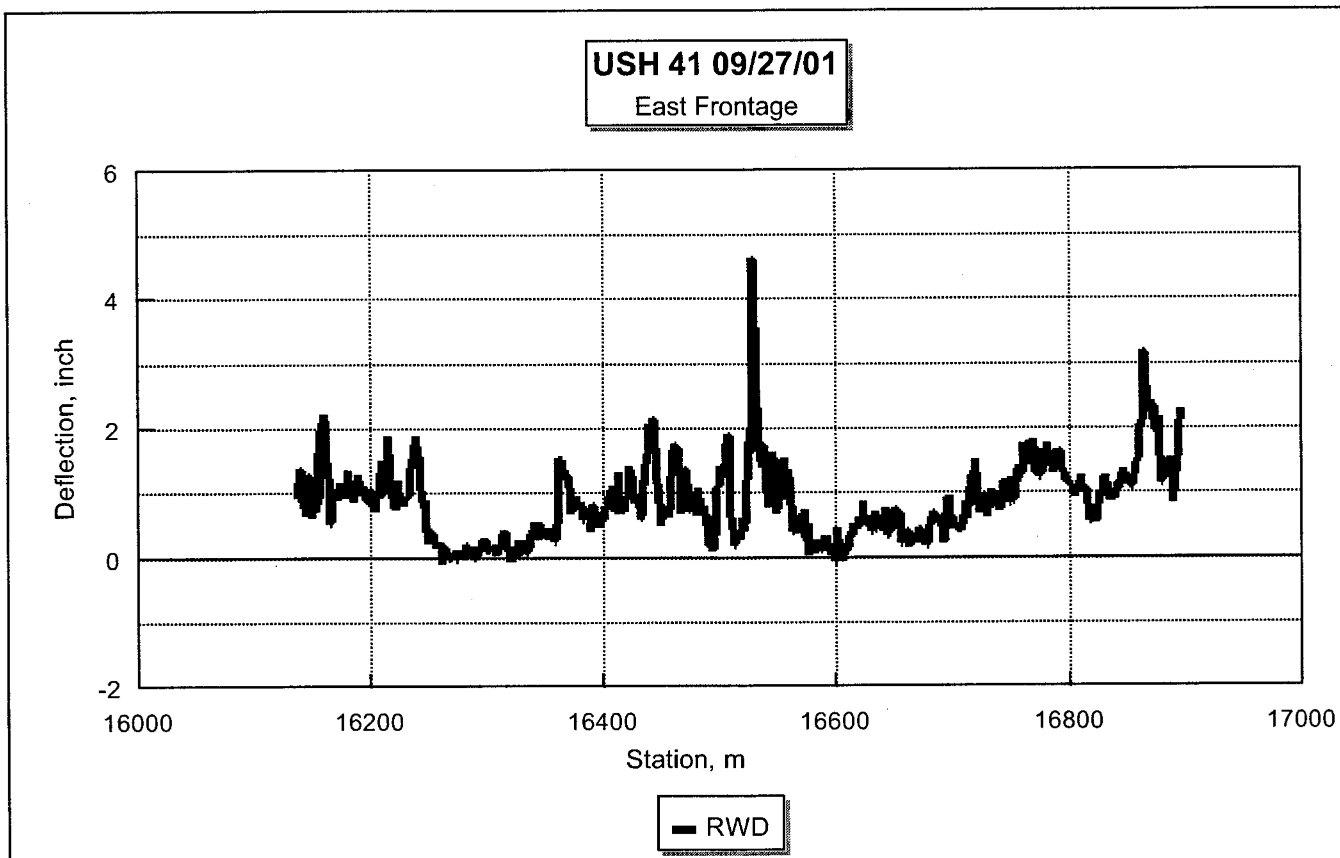

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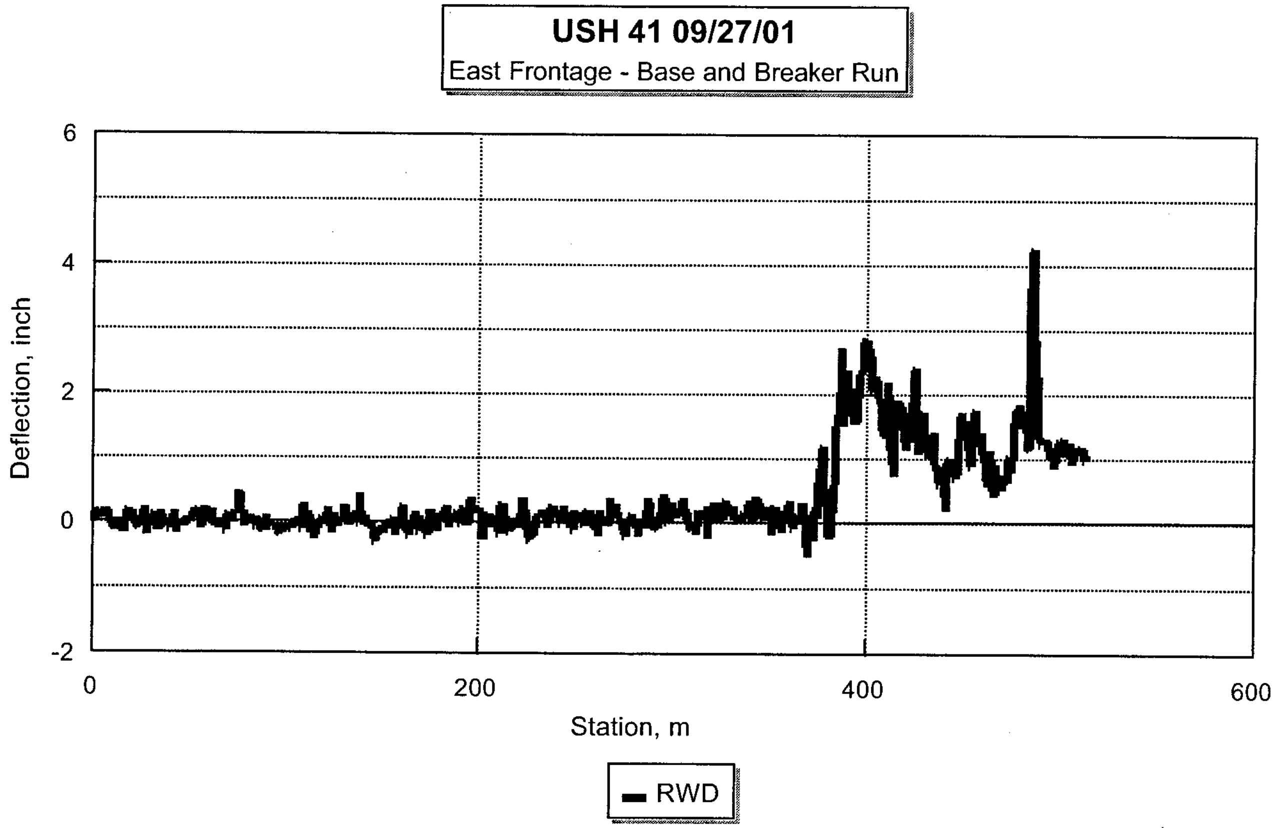
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-2
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200
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600
Station, m
RWD
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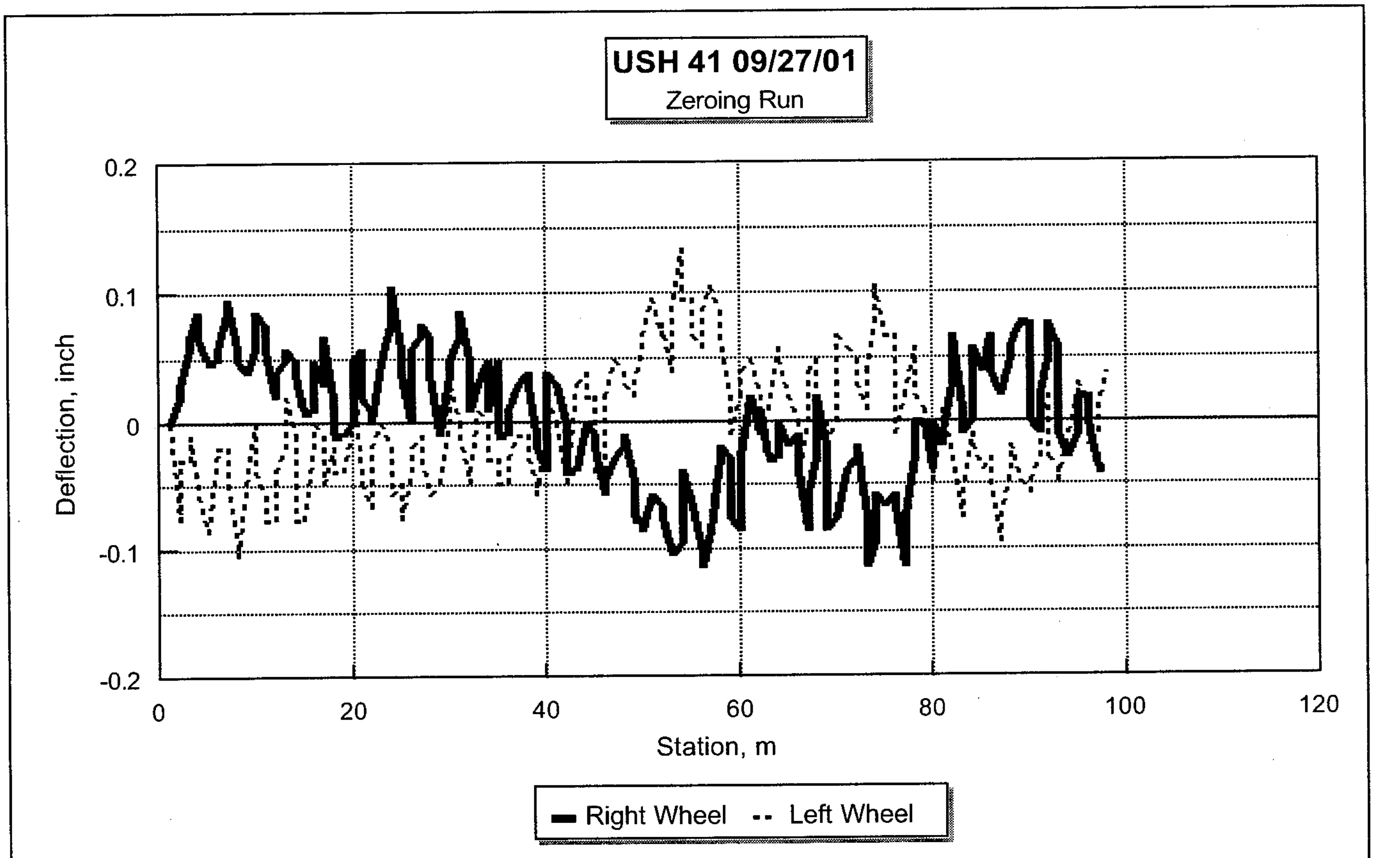

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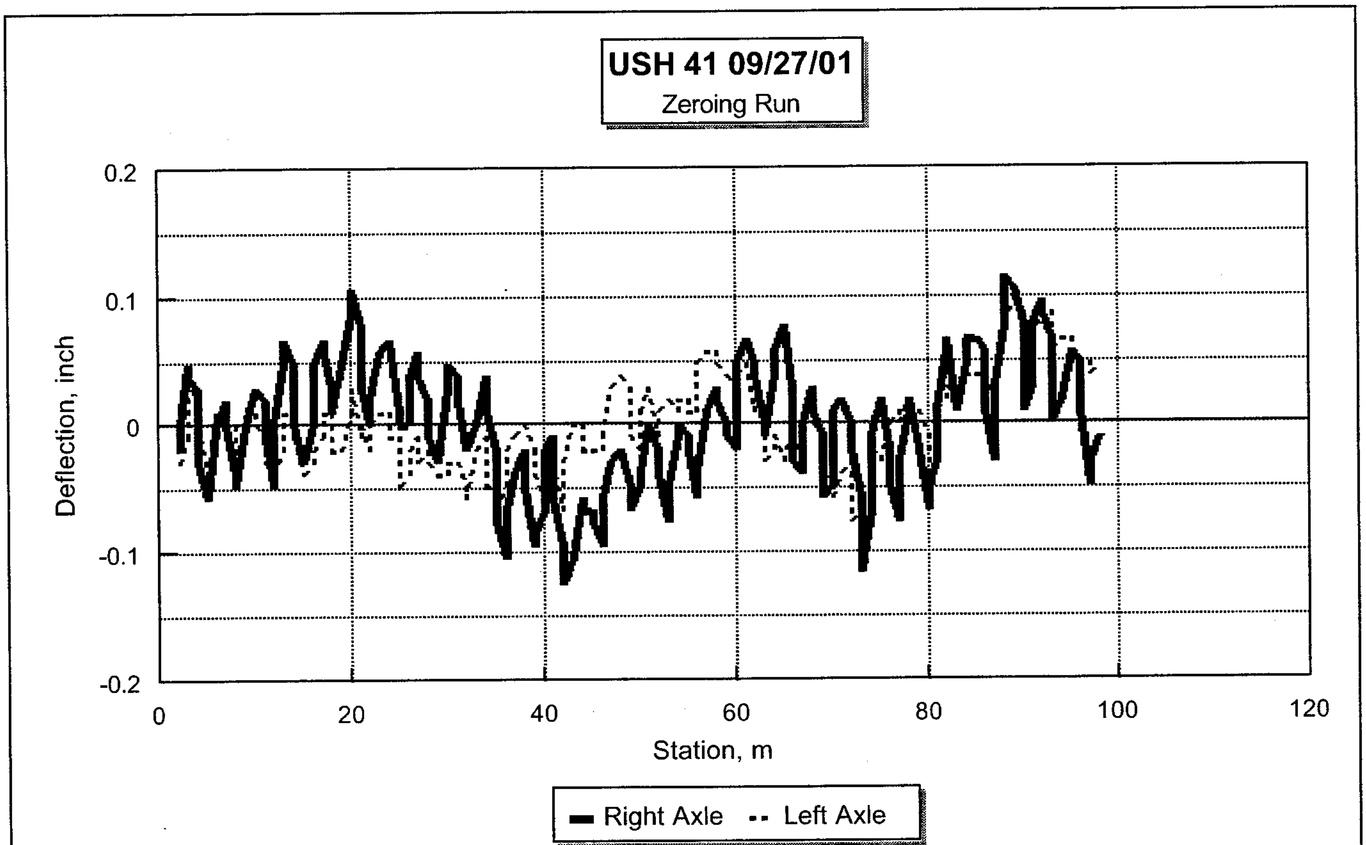

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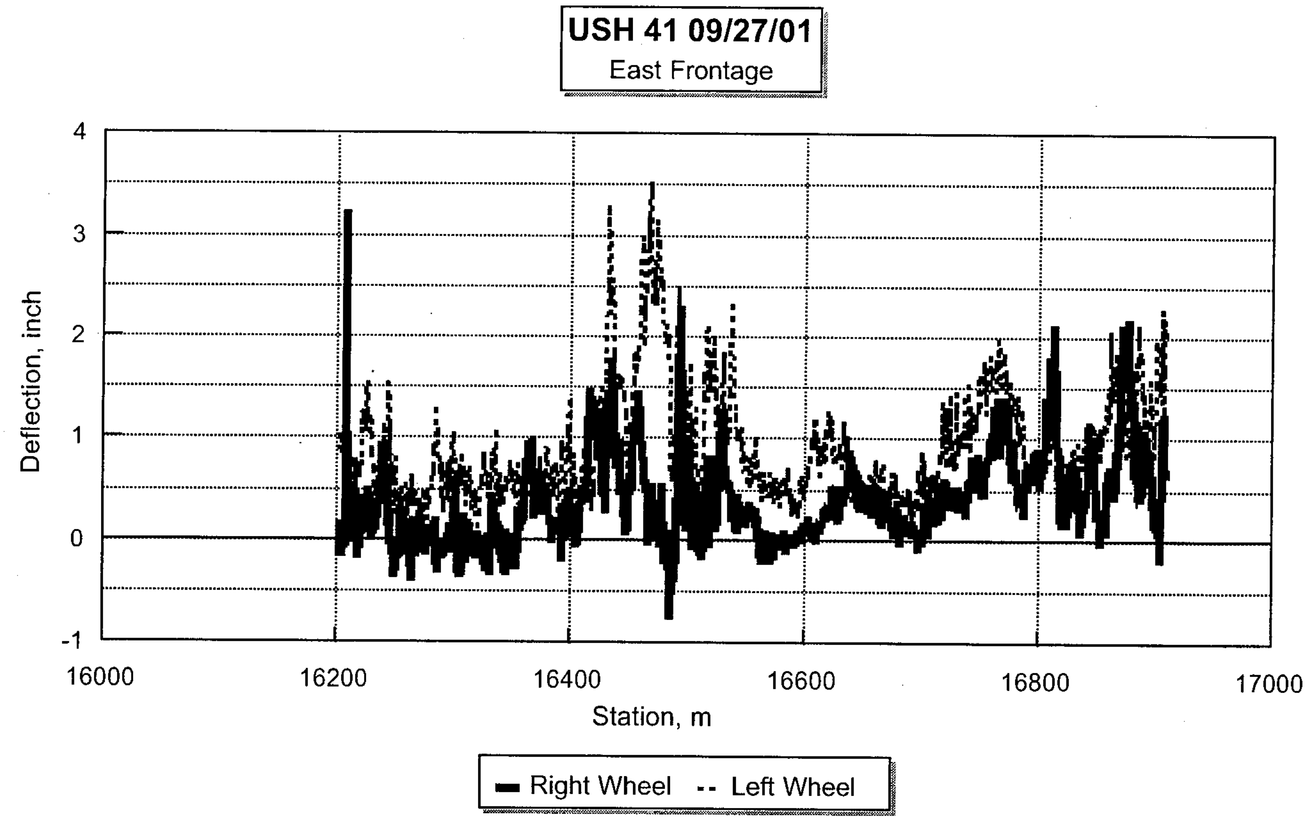

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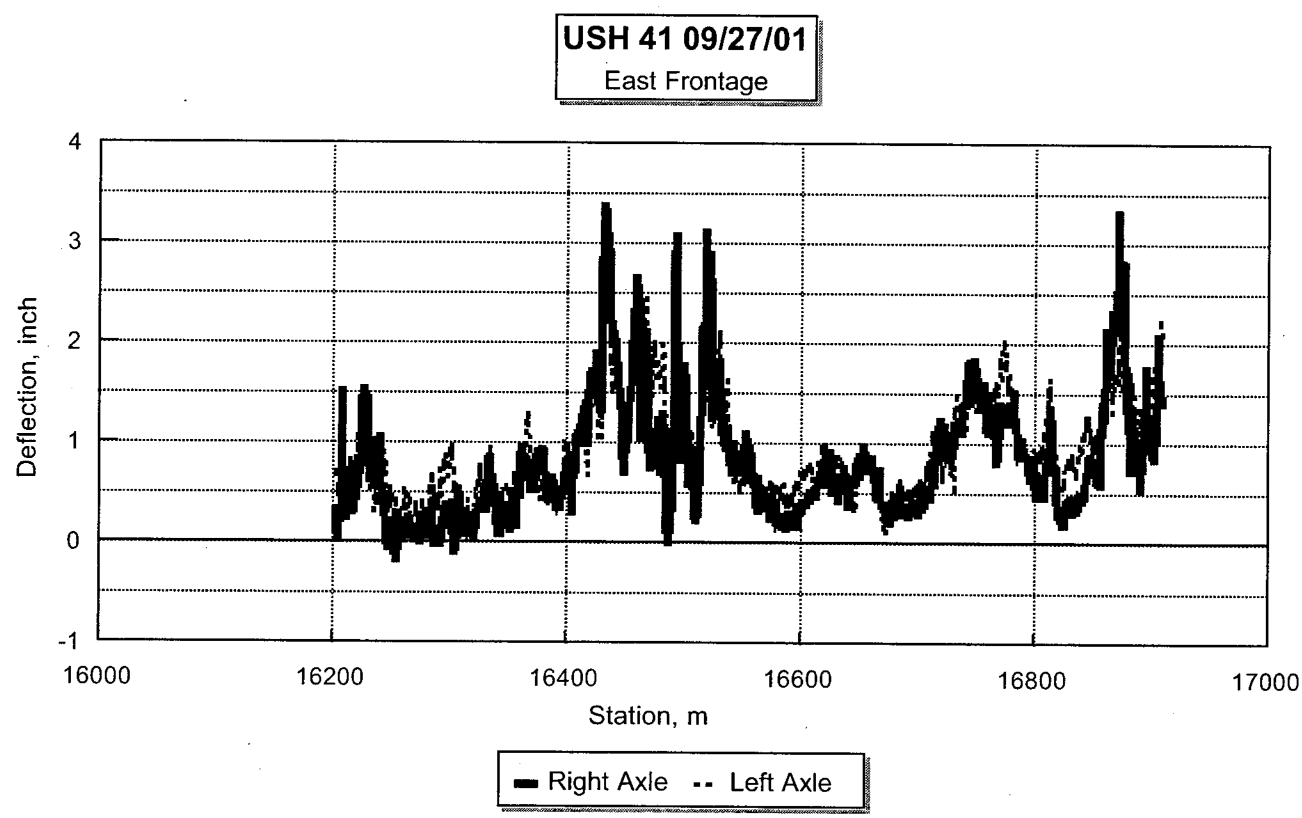

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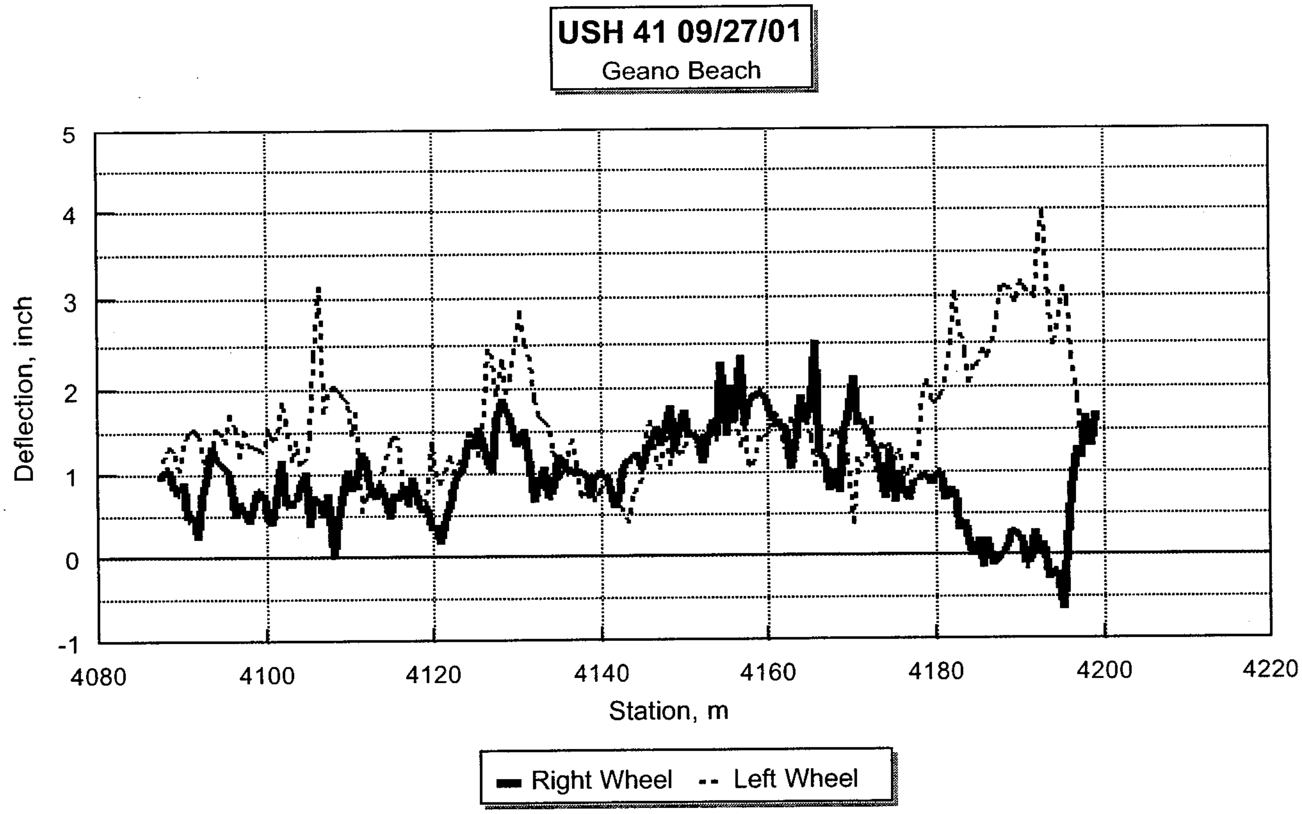

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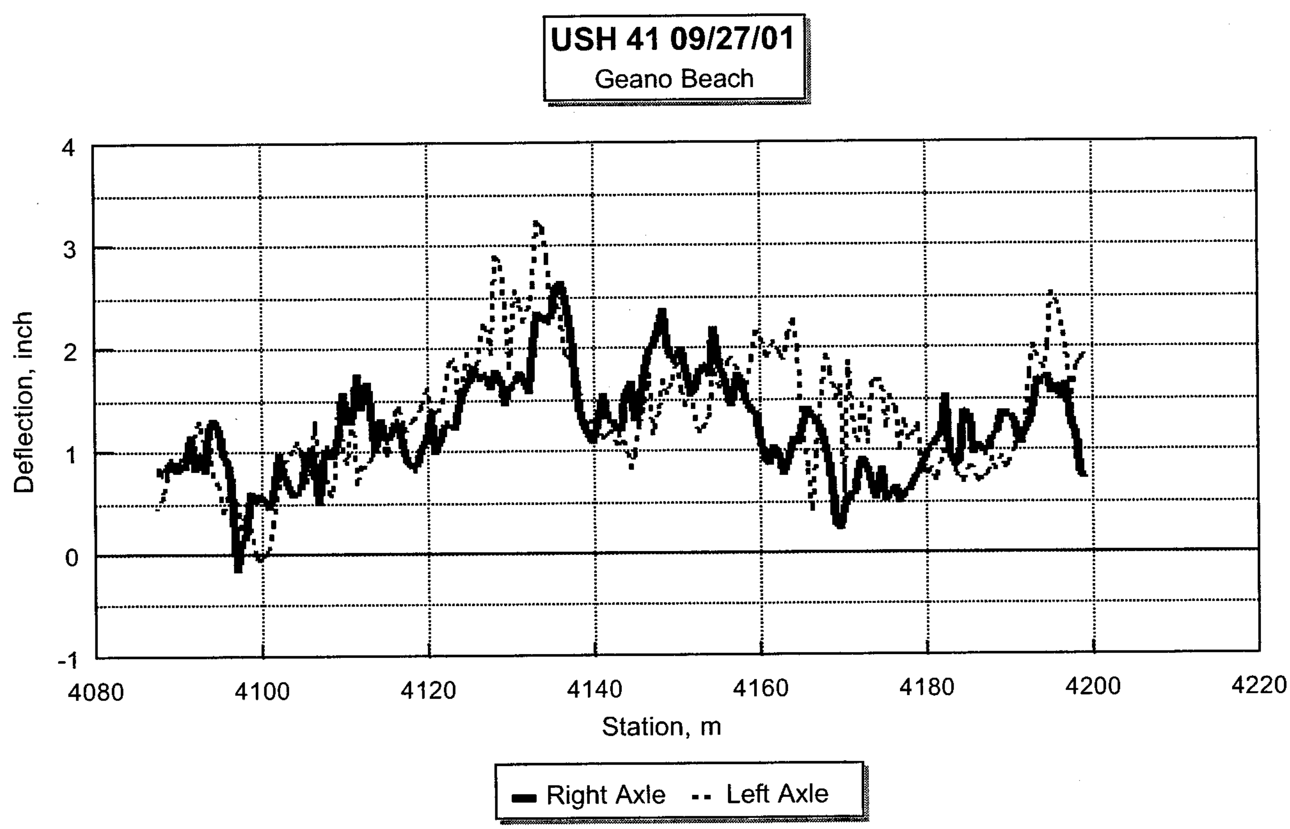

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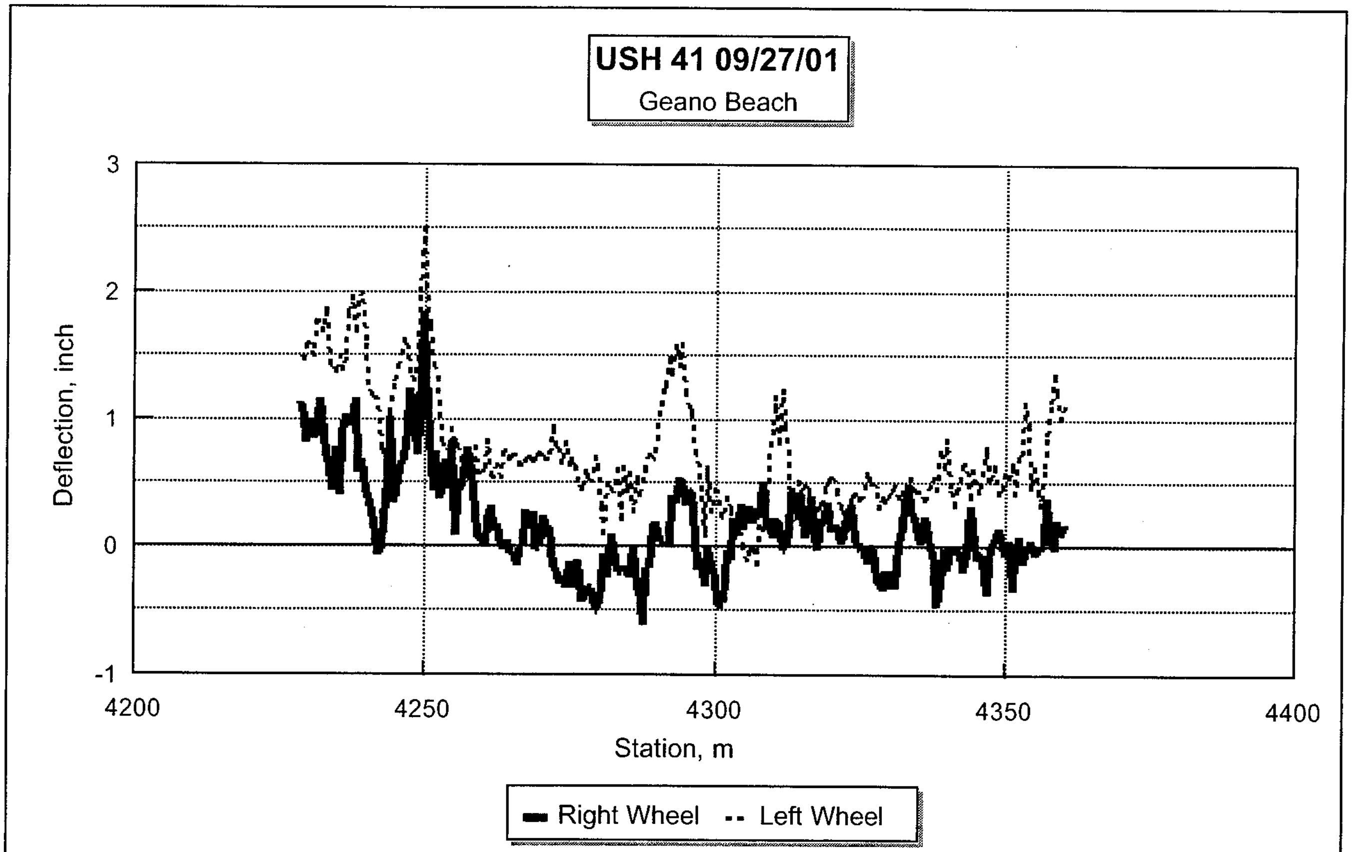

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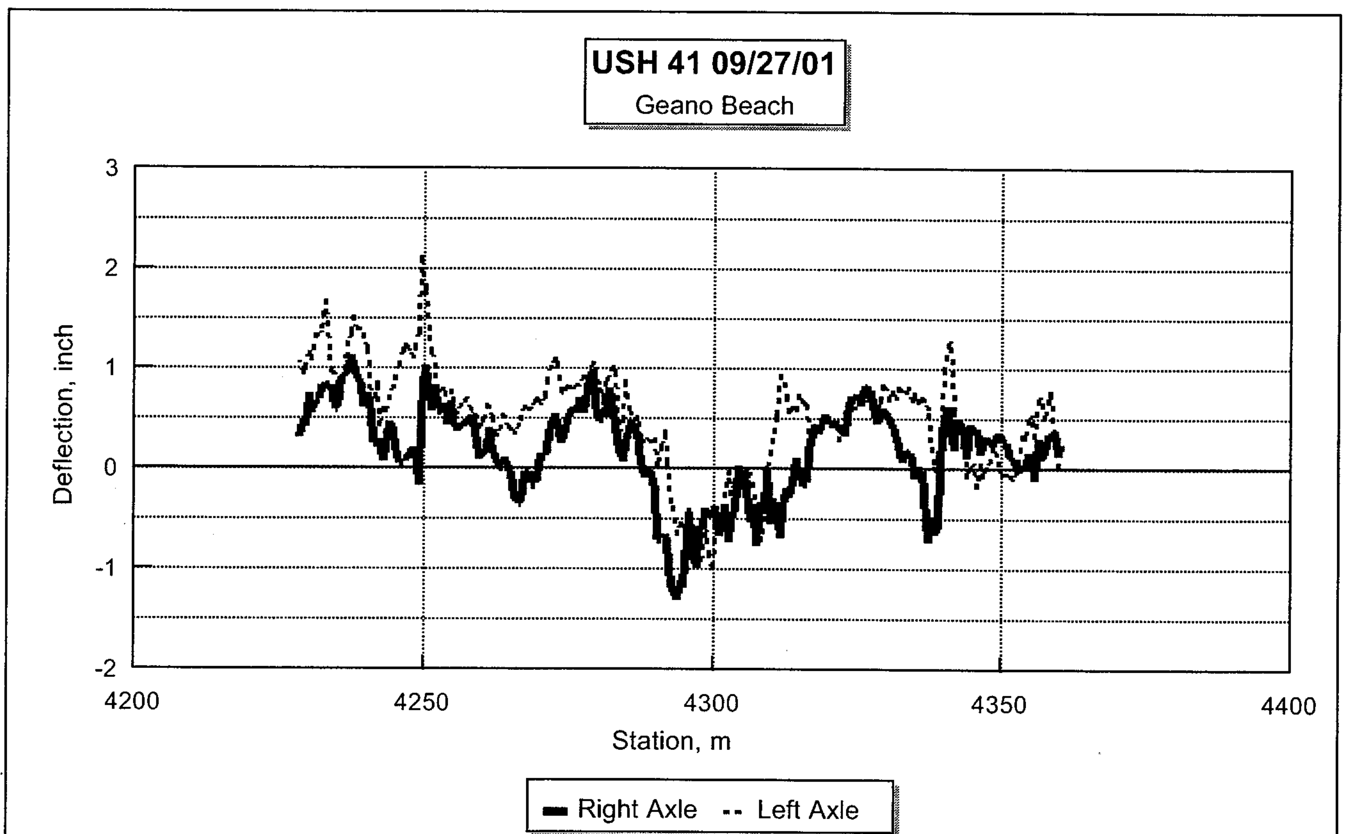

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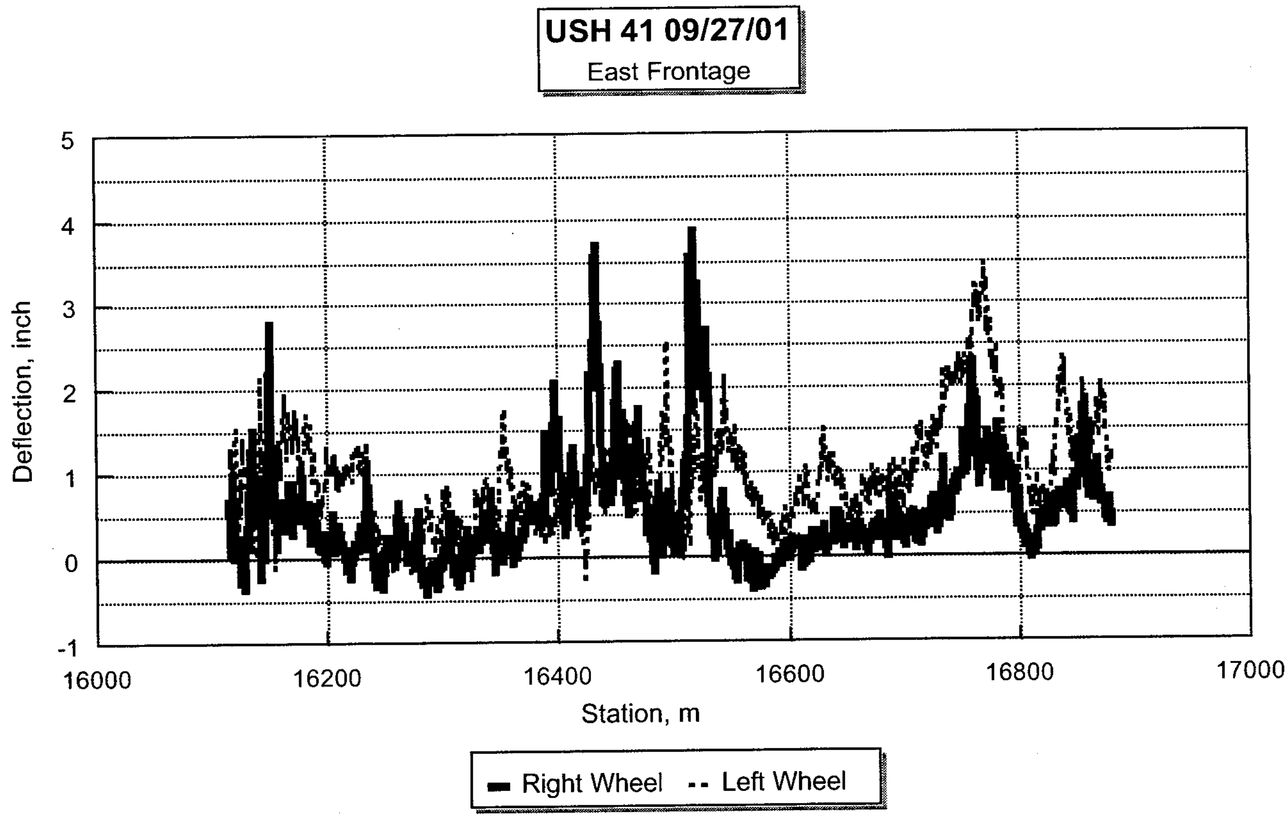

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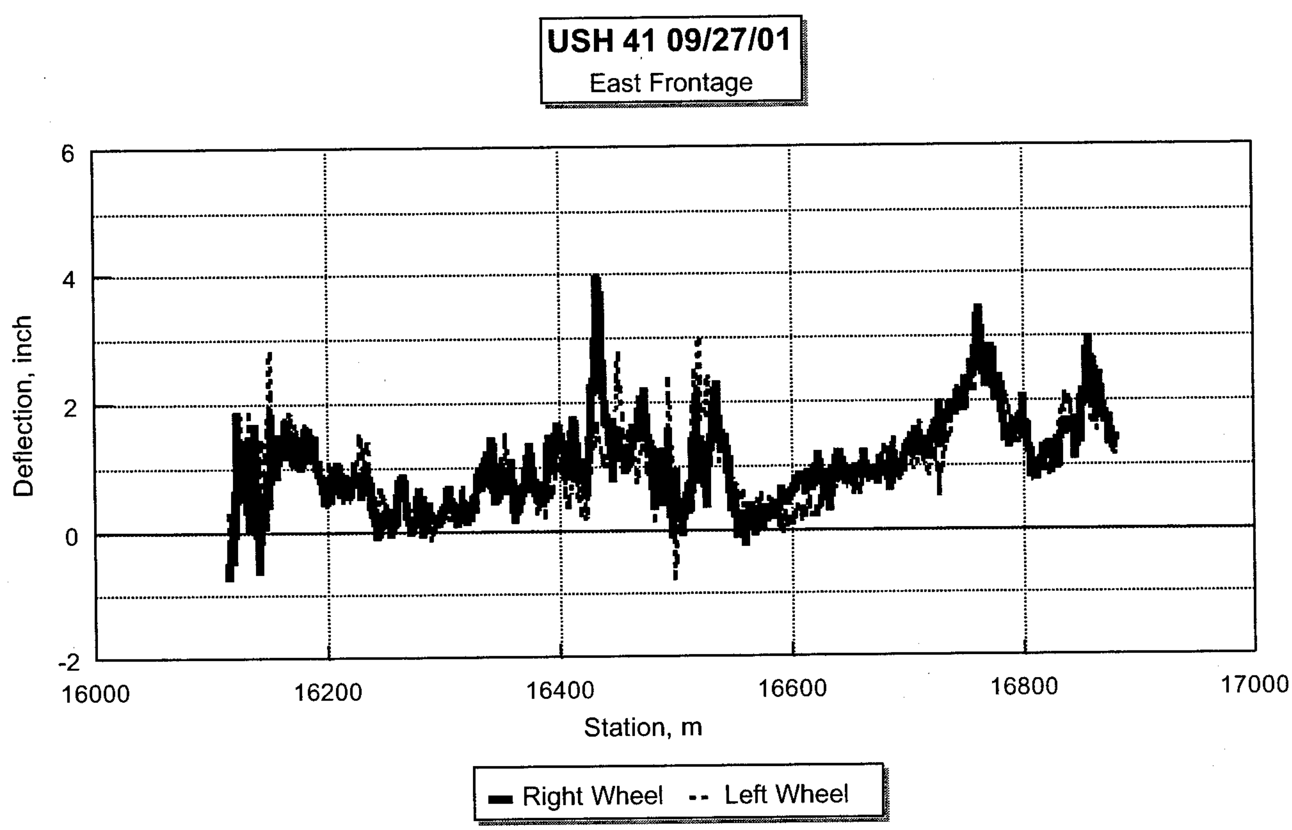

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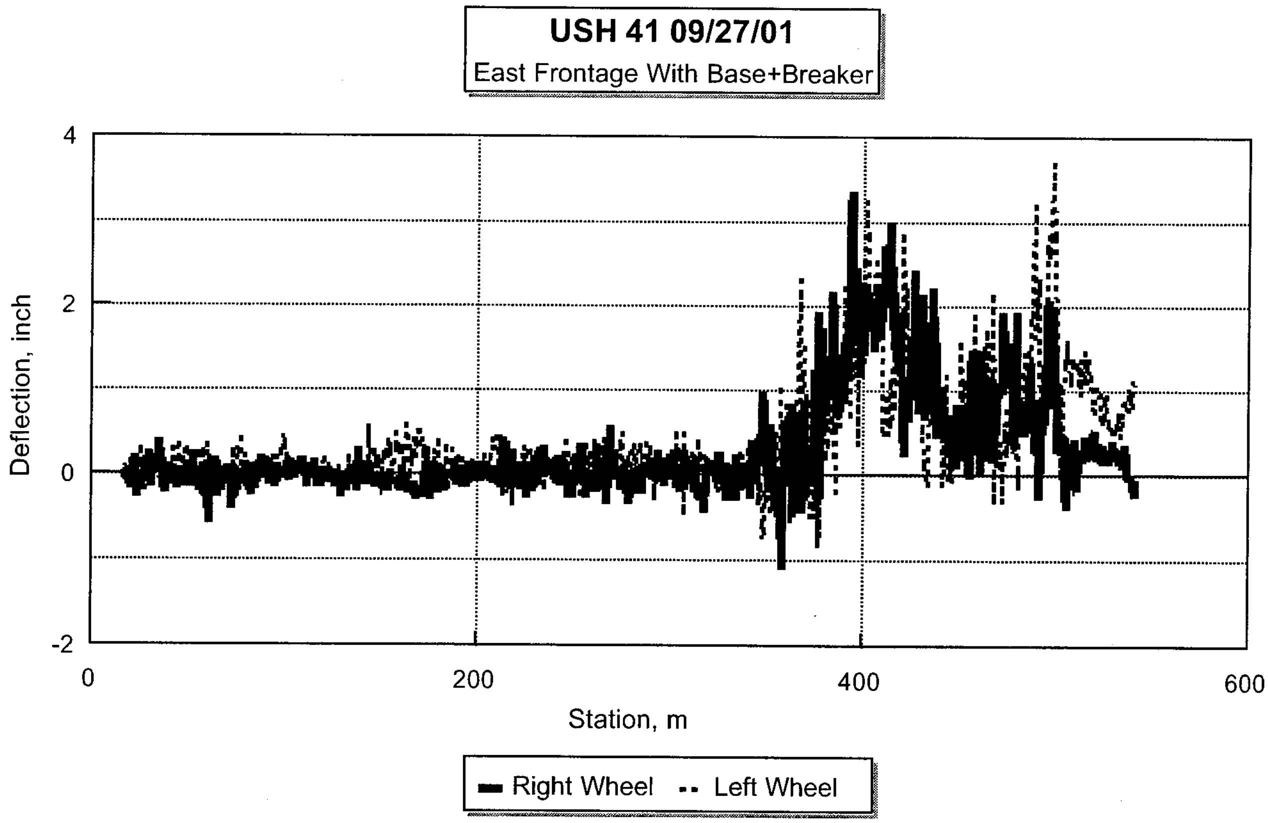

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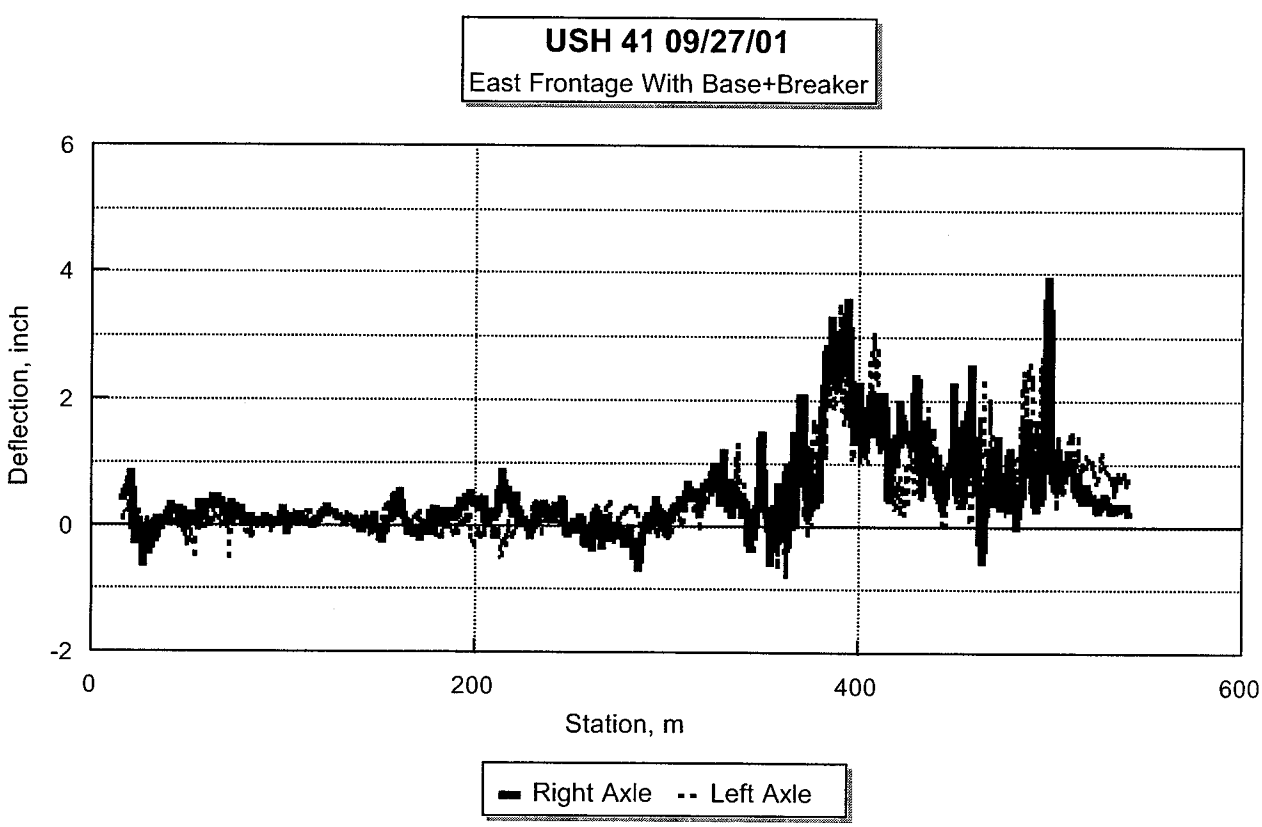

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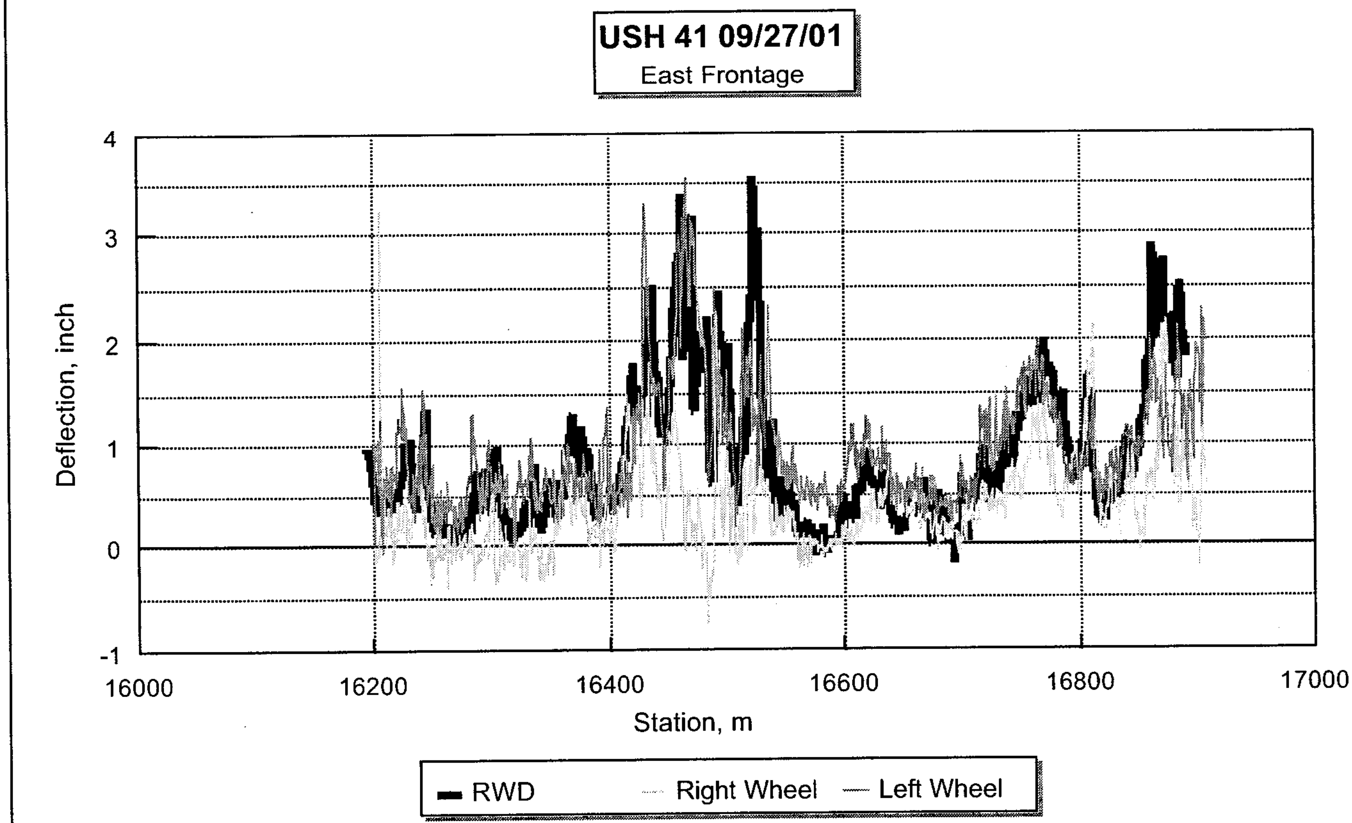

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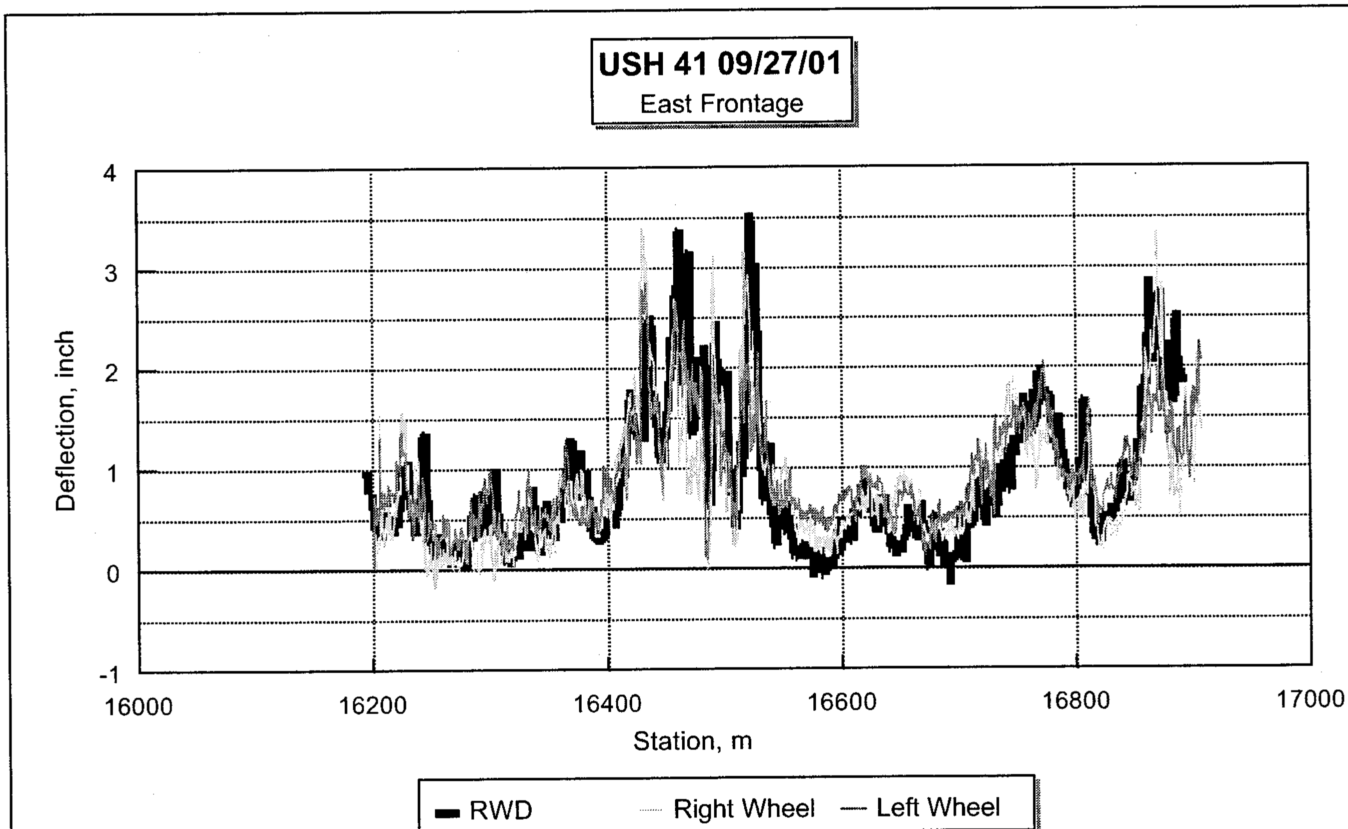

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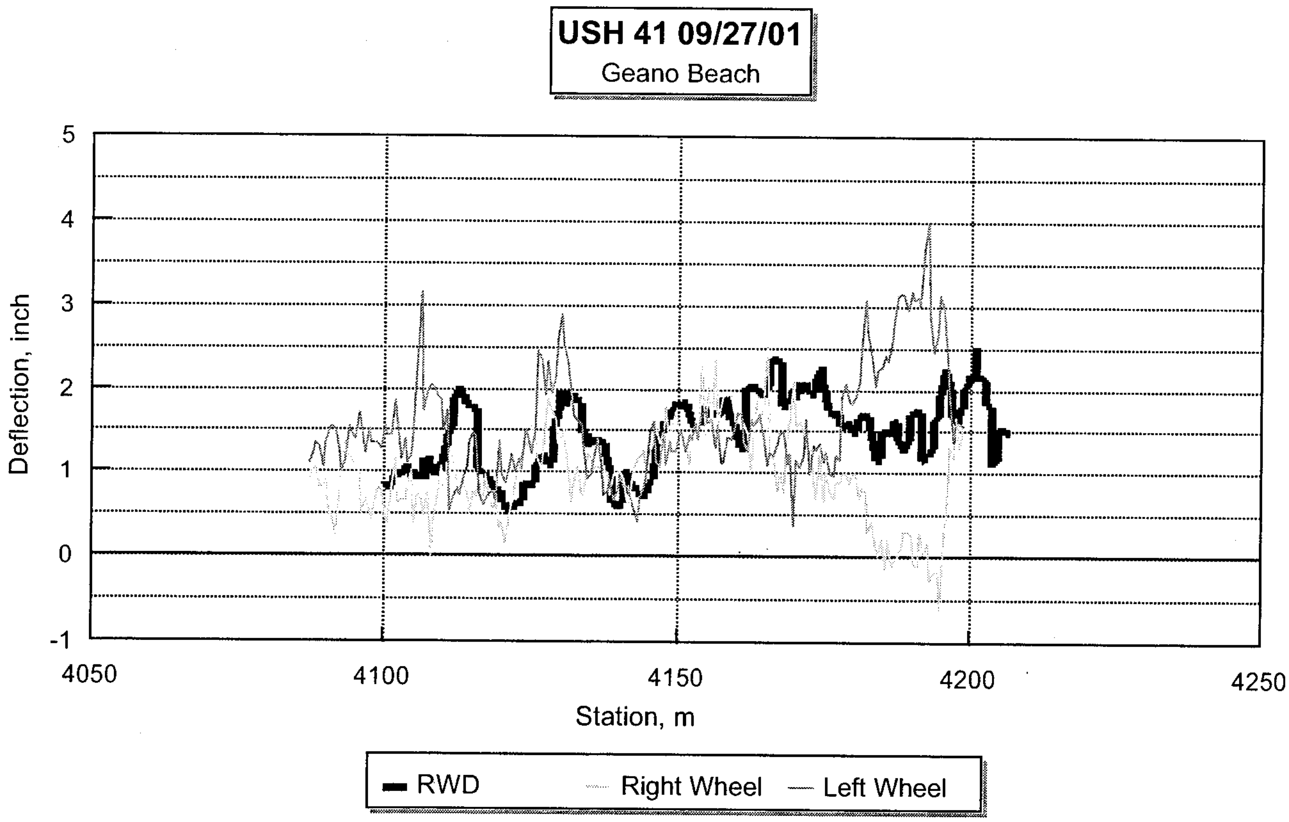

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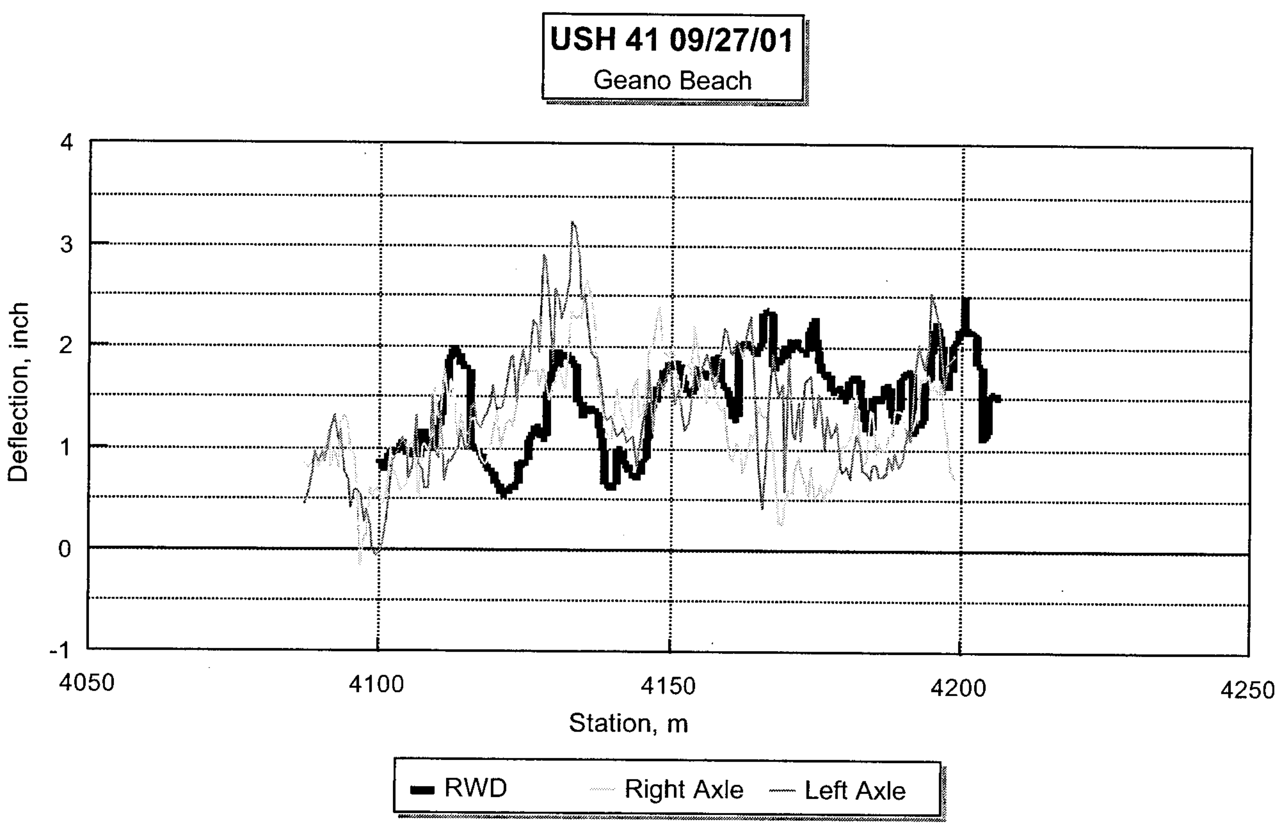

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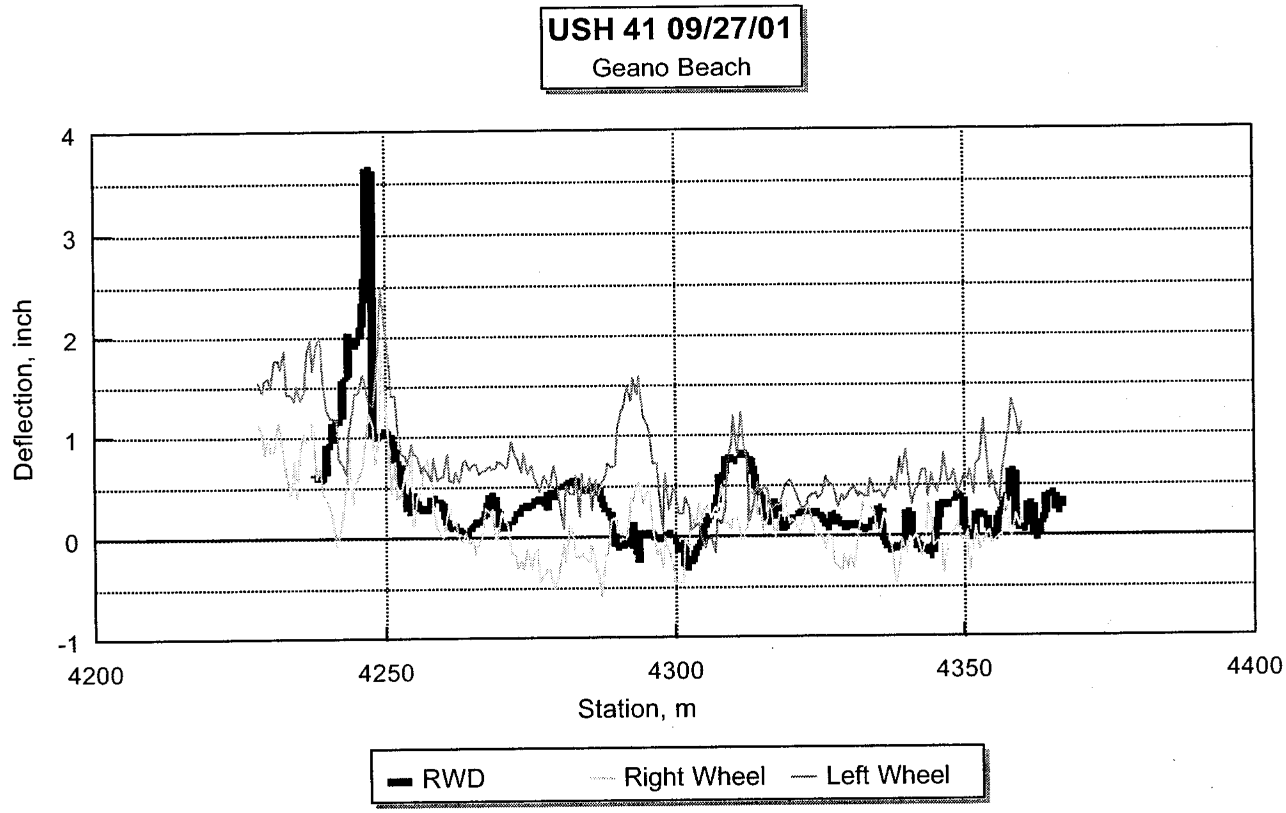

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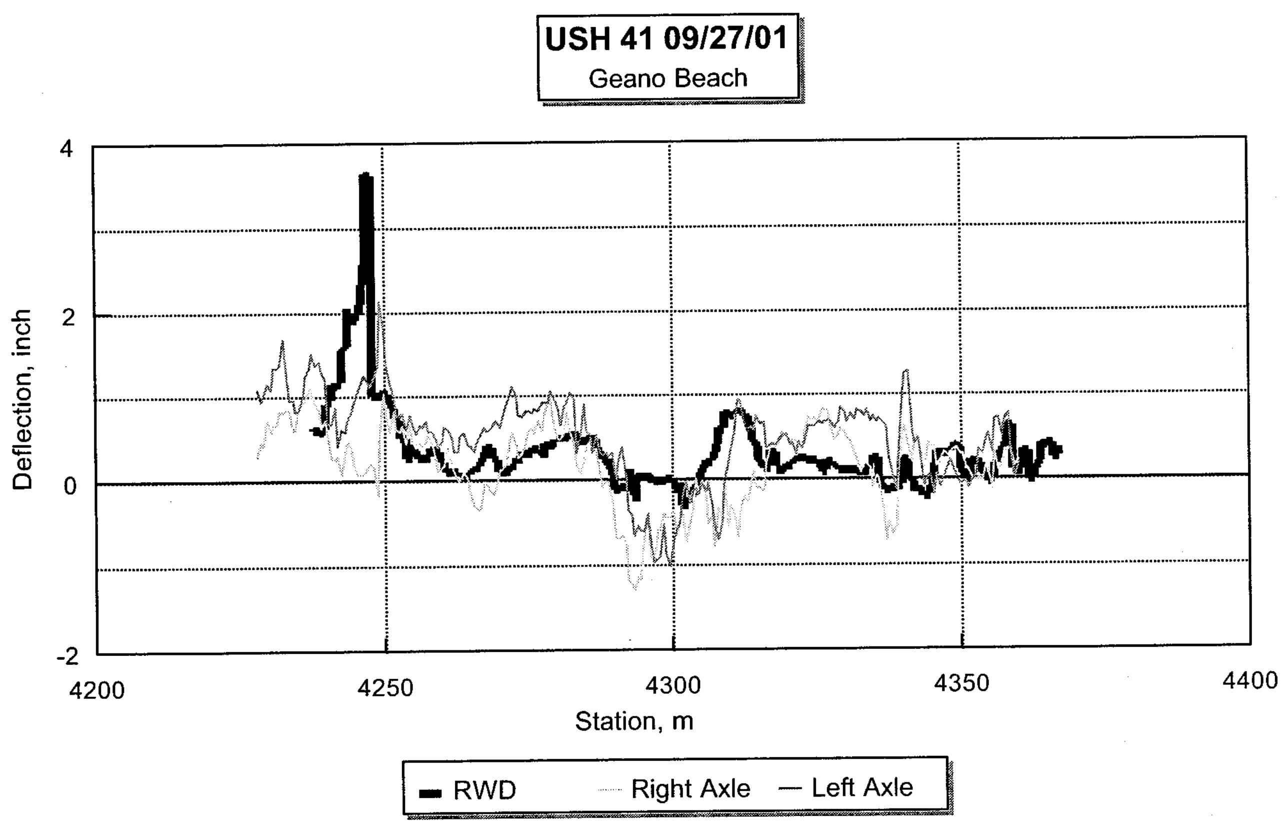

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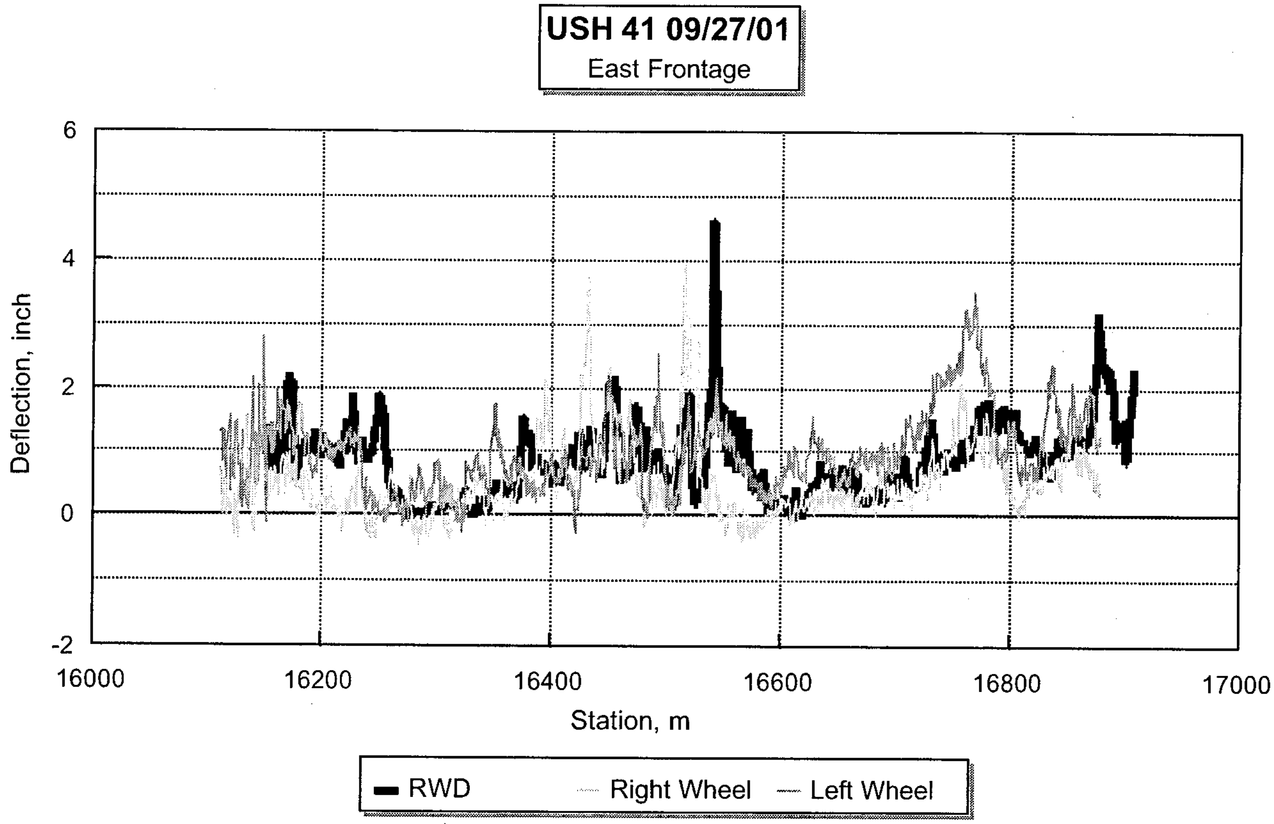

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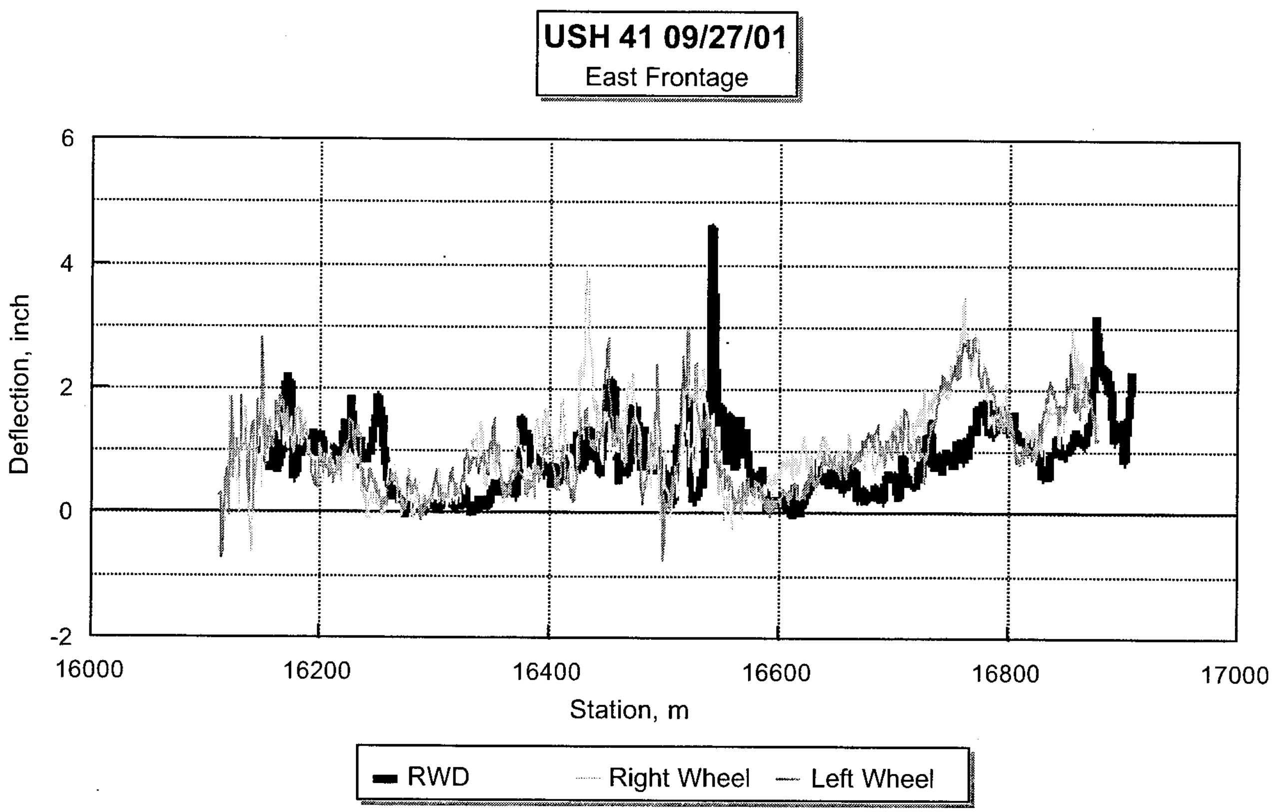

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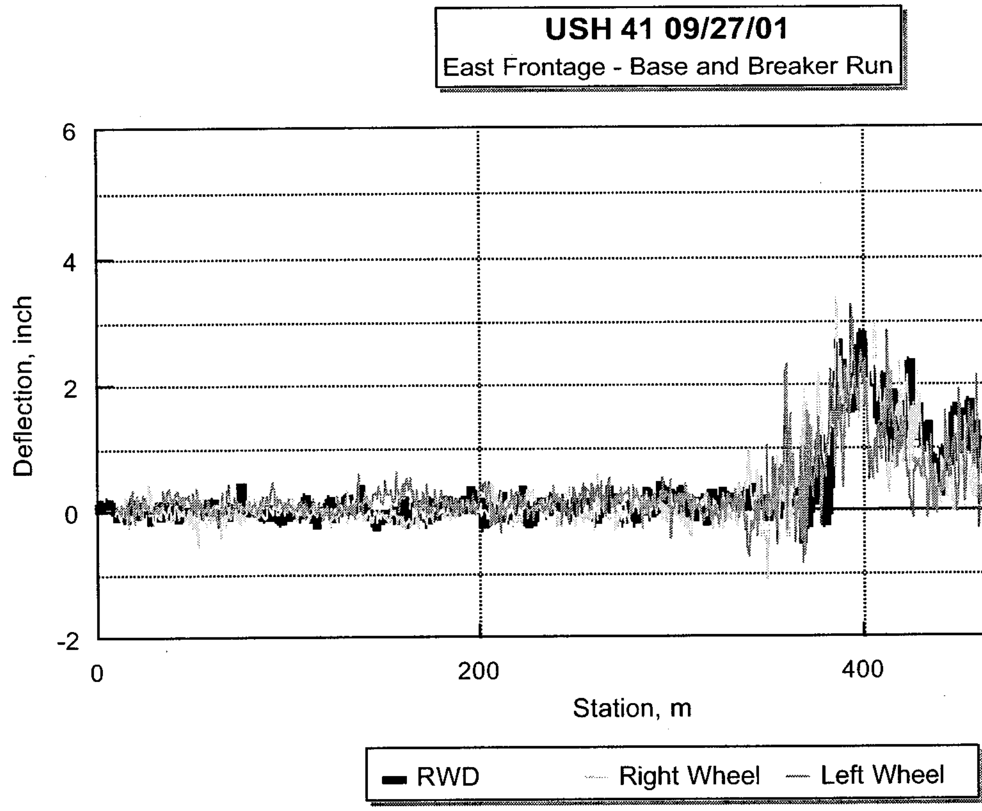

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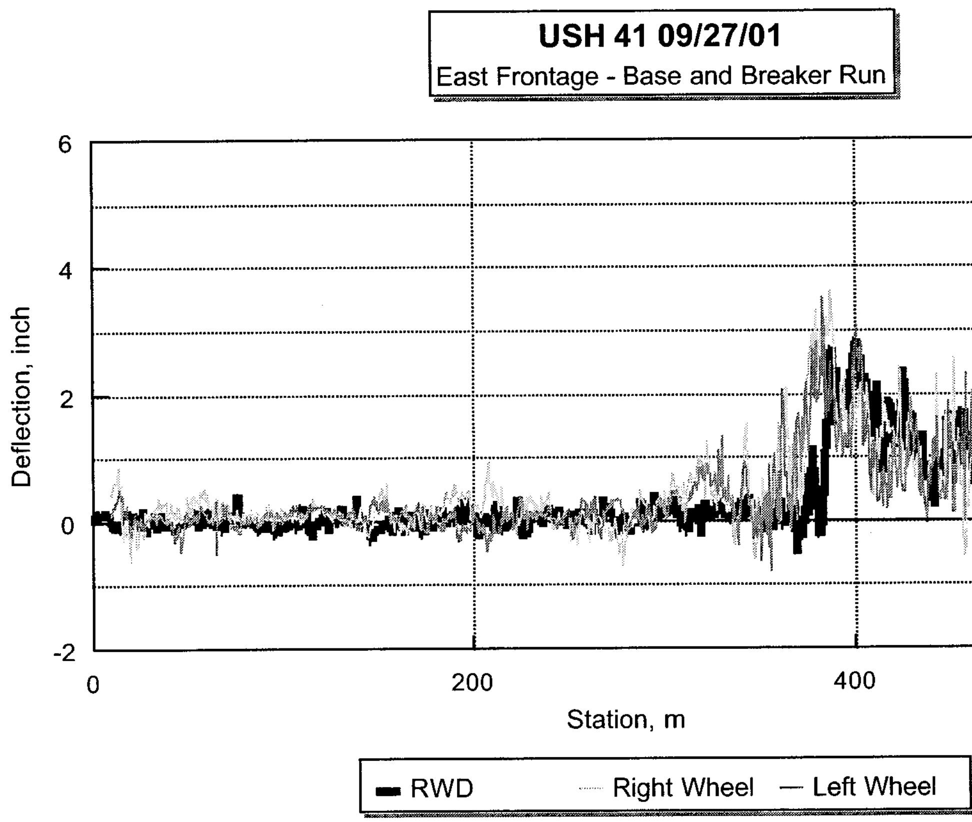

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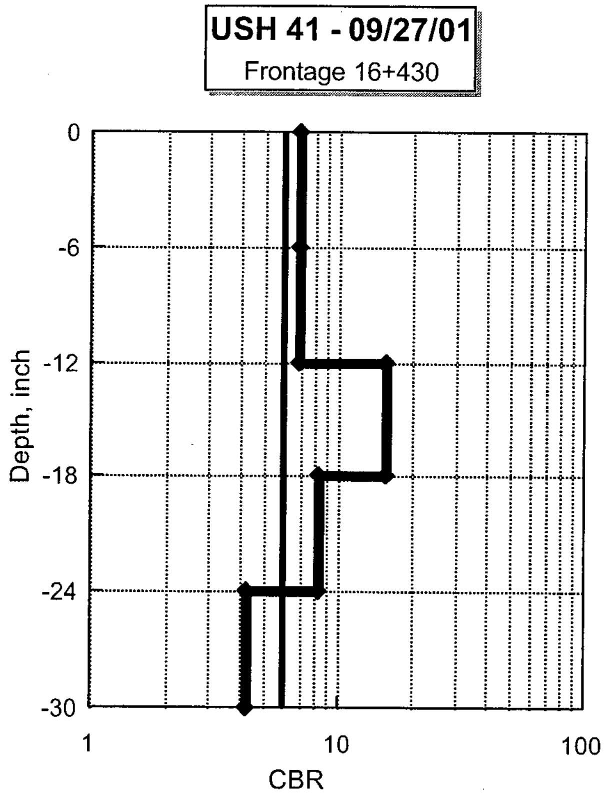

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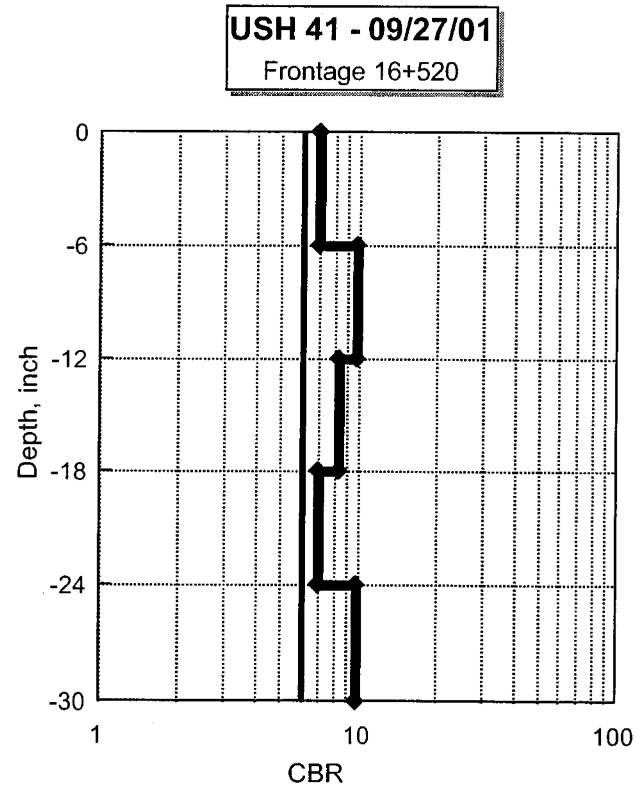

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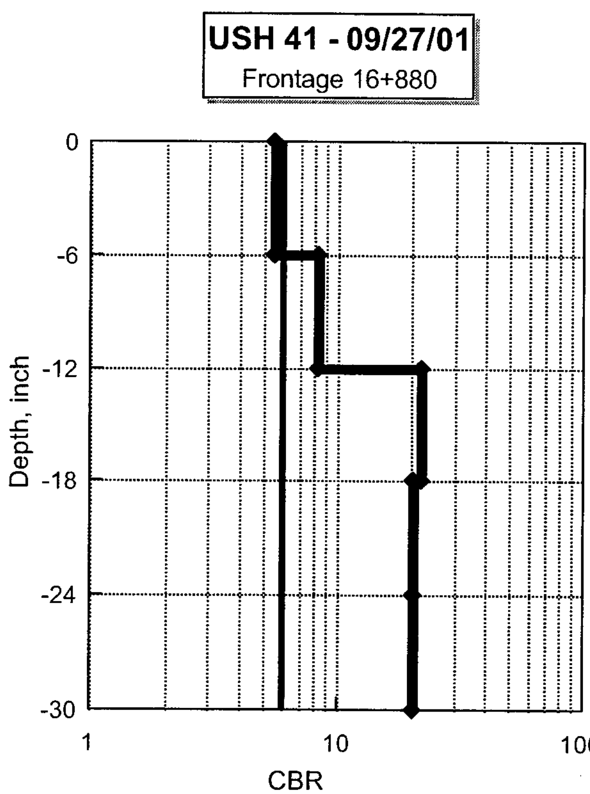

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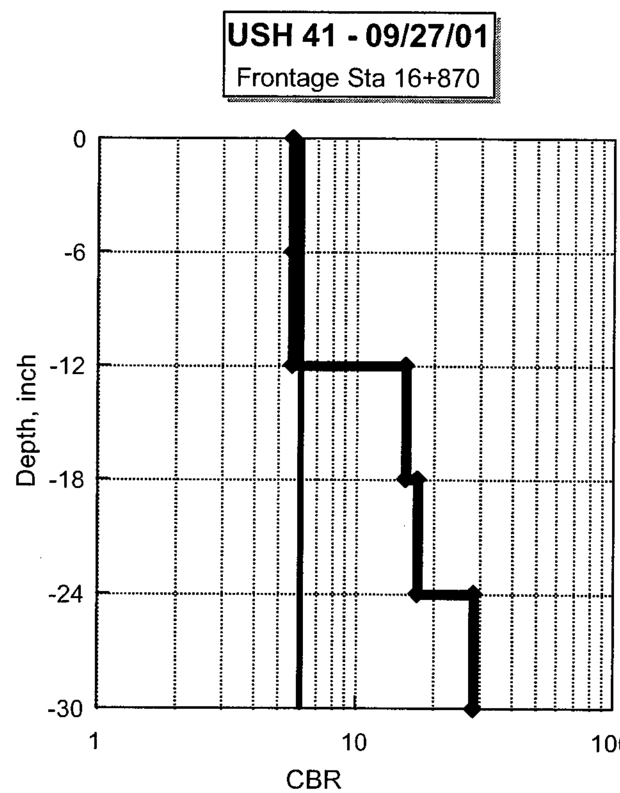

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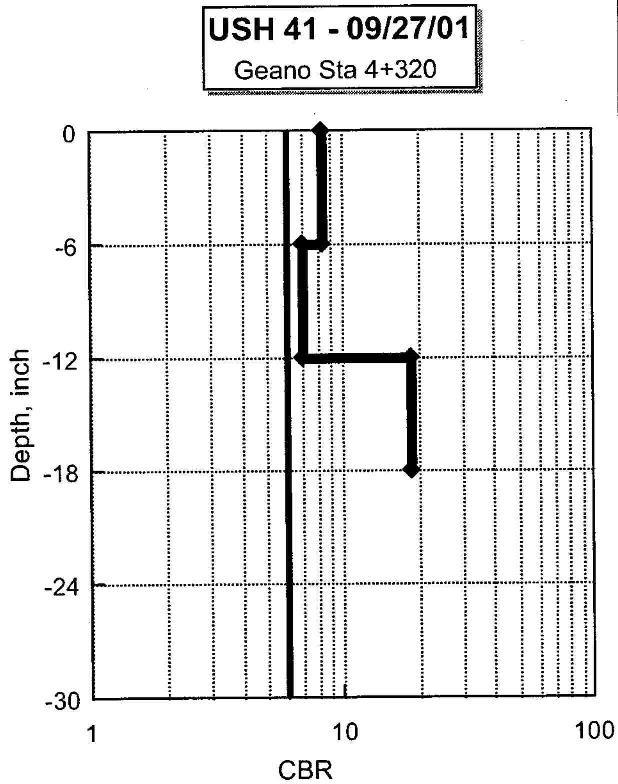

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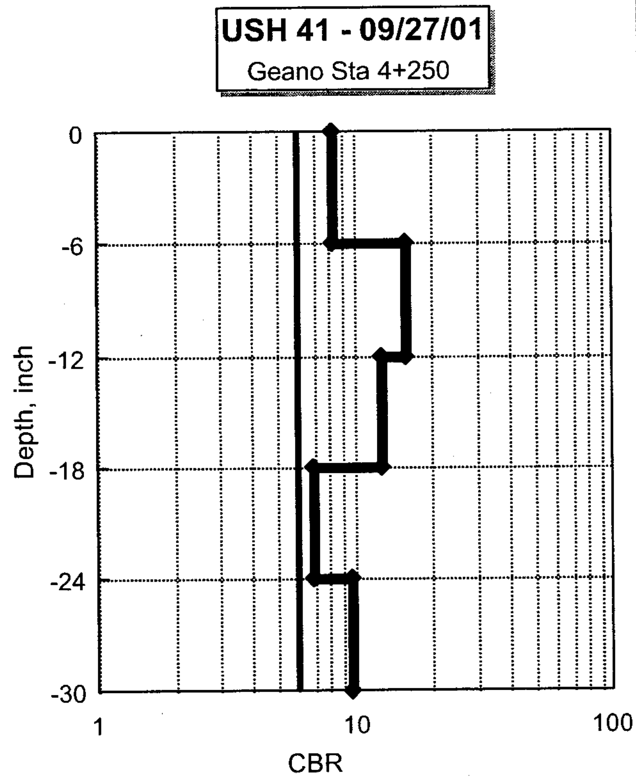

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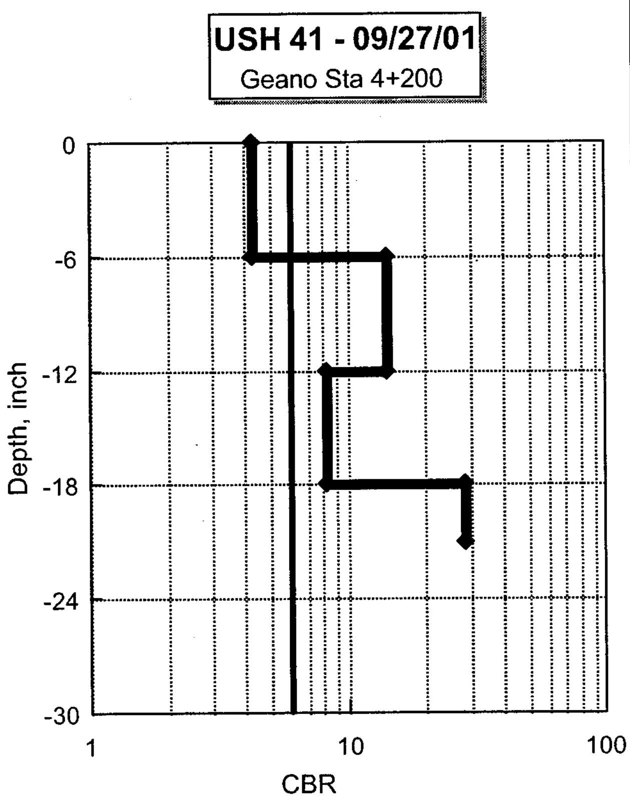

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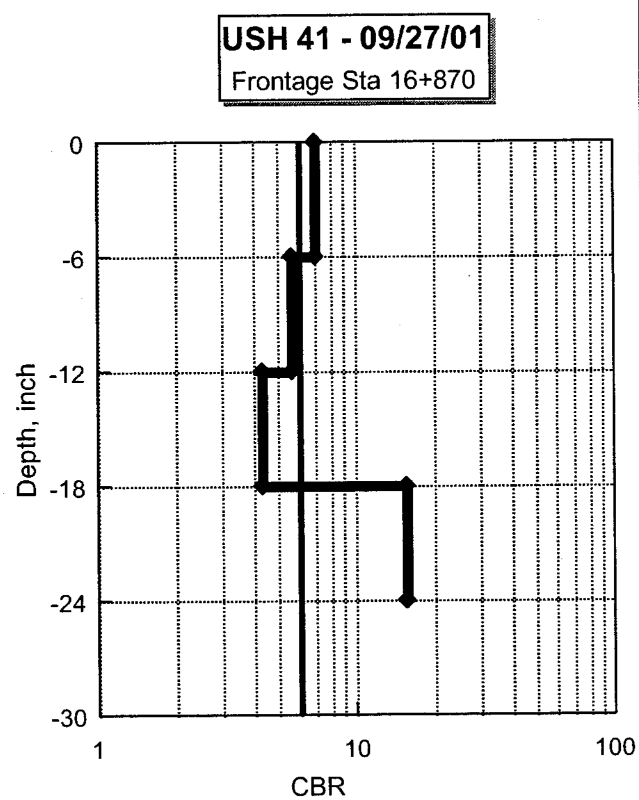

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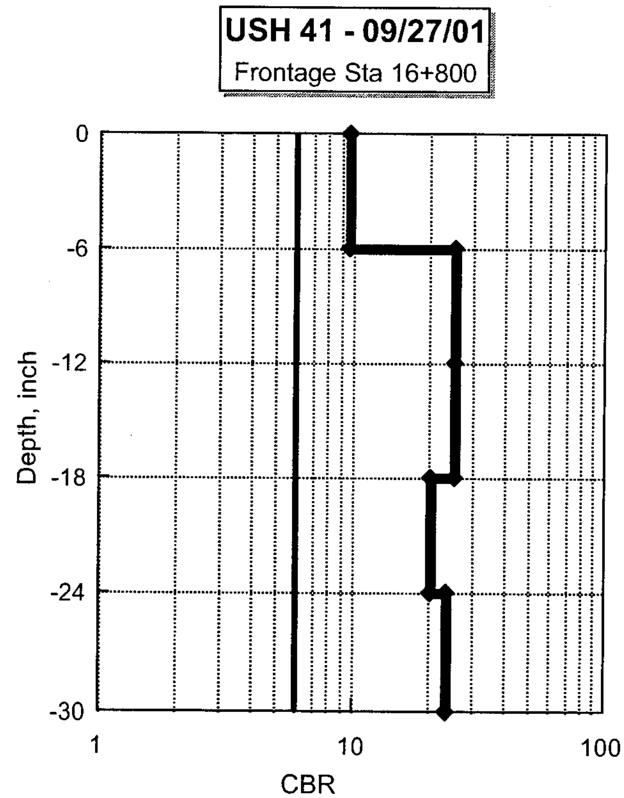

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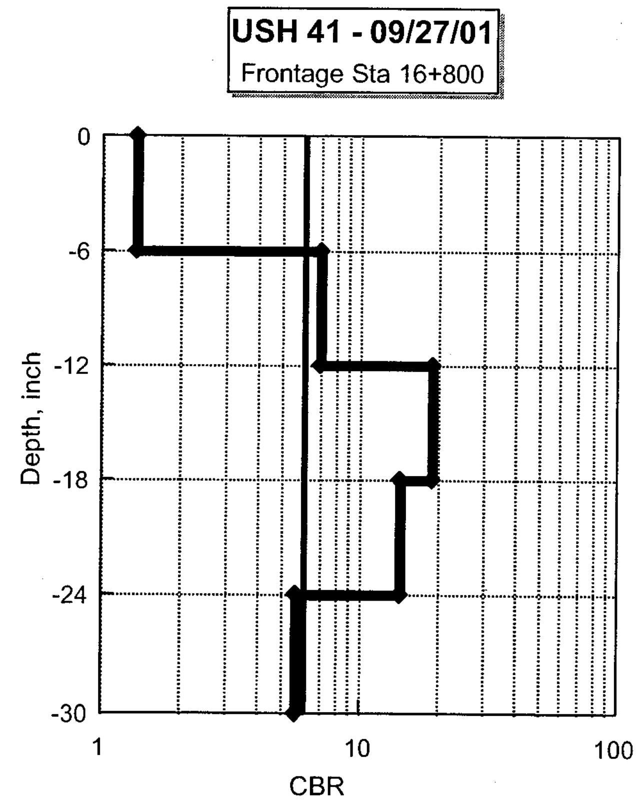

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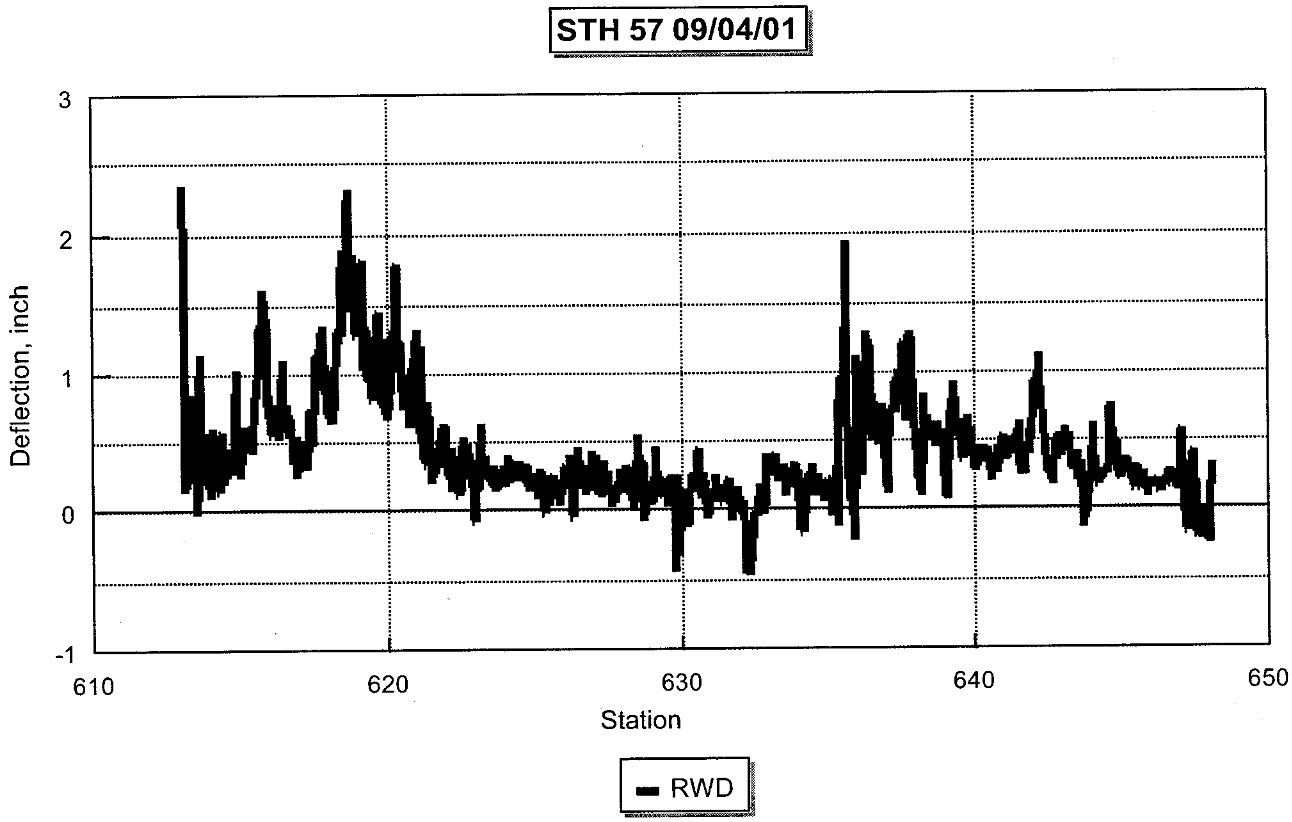

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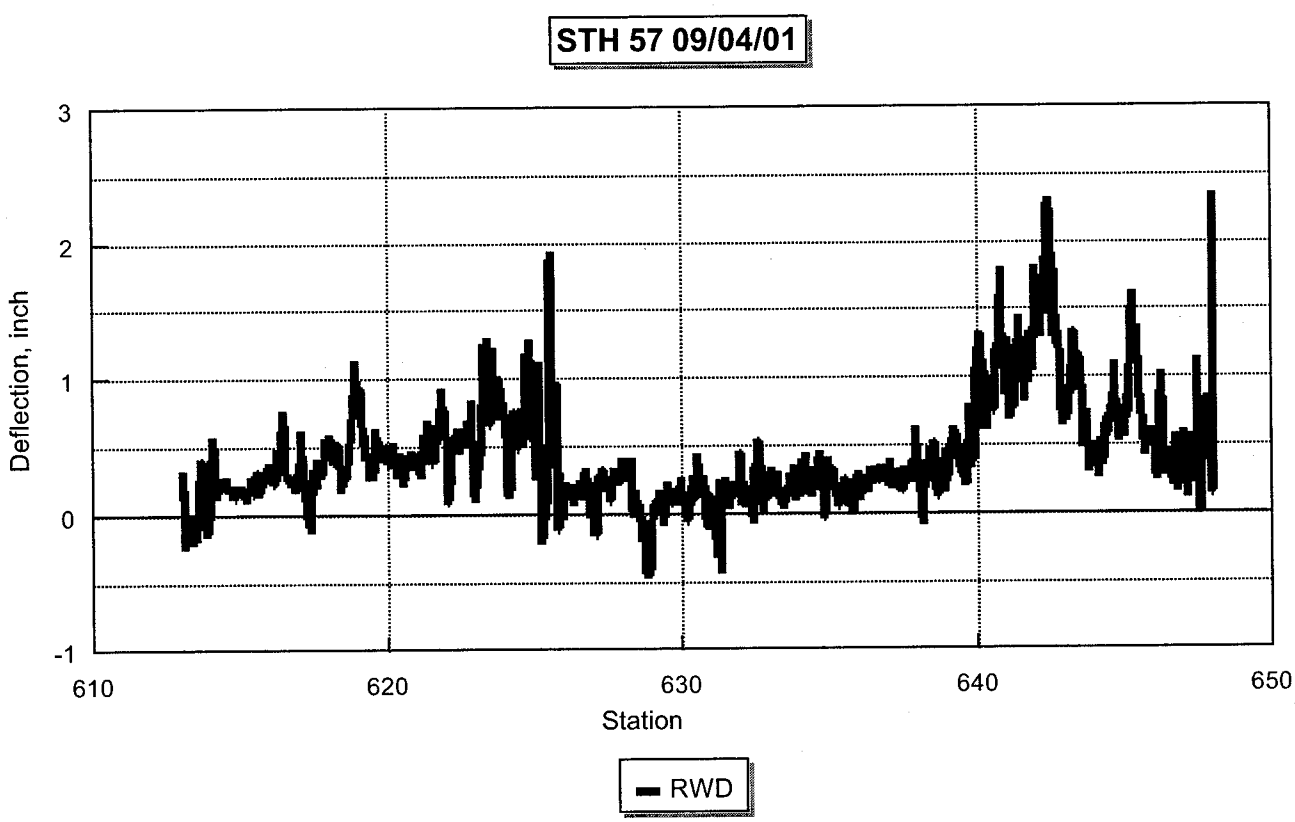

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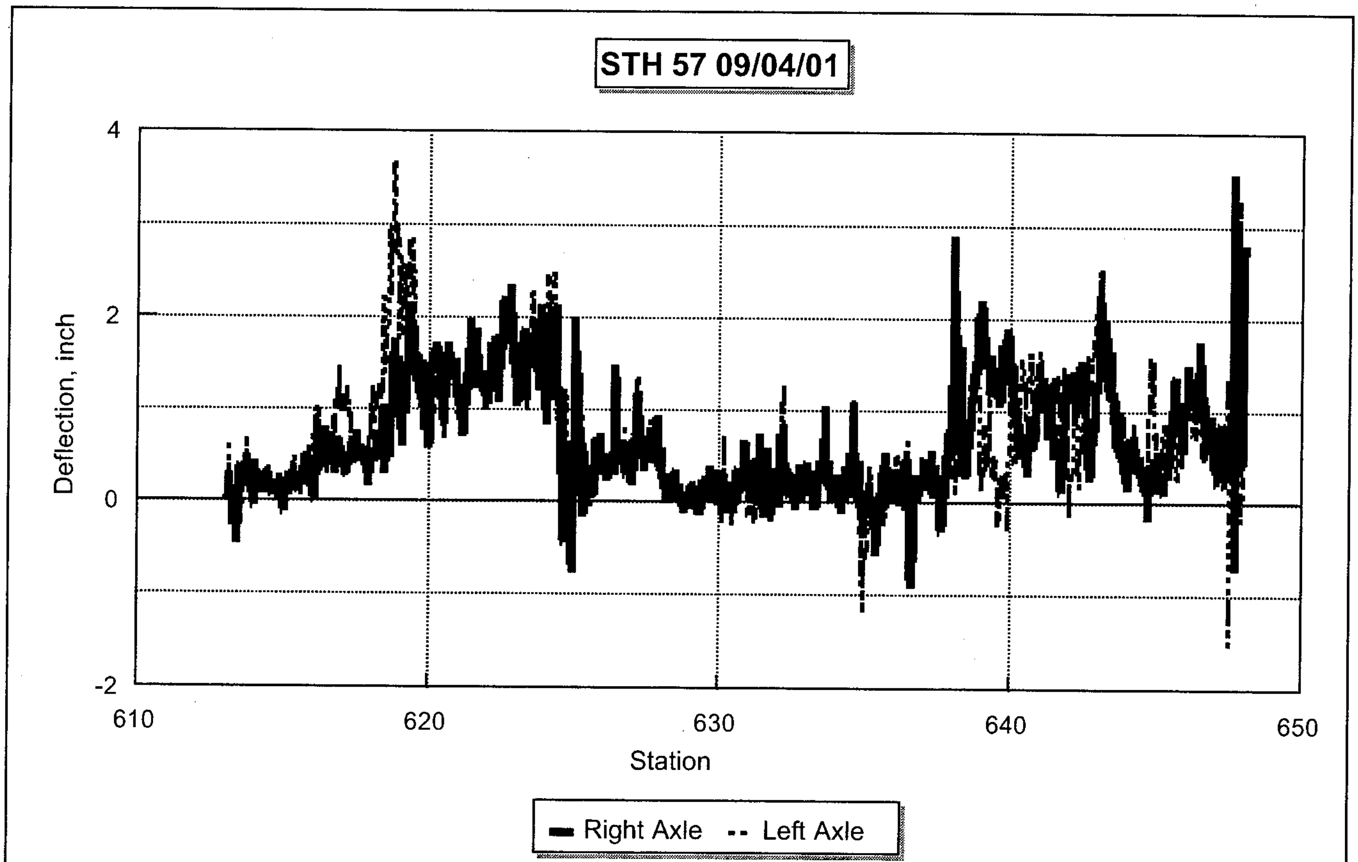

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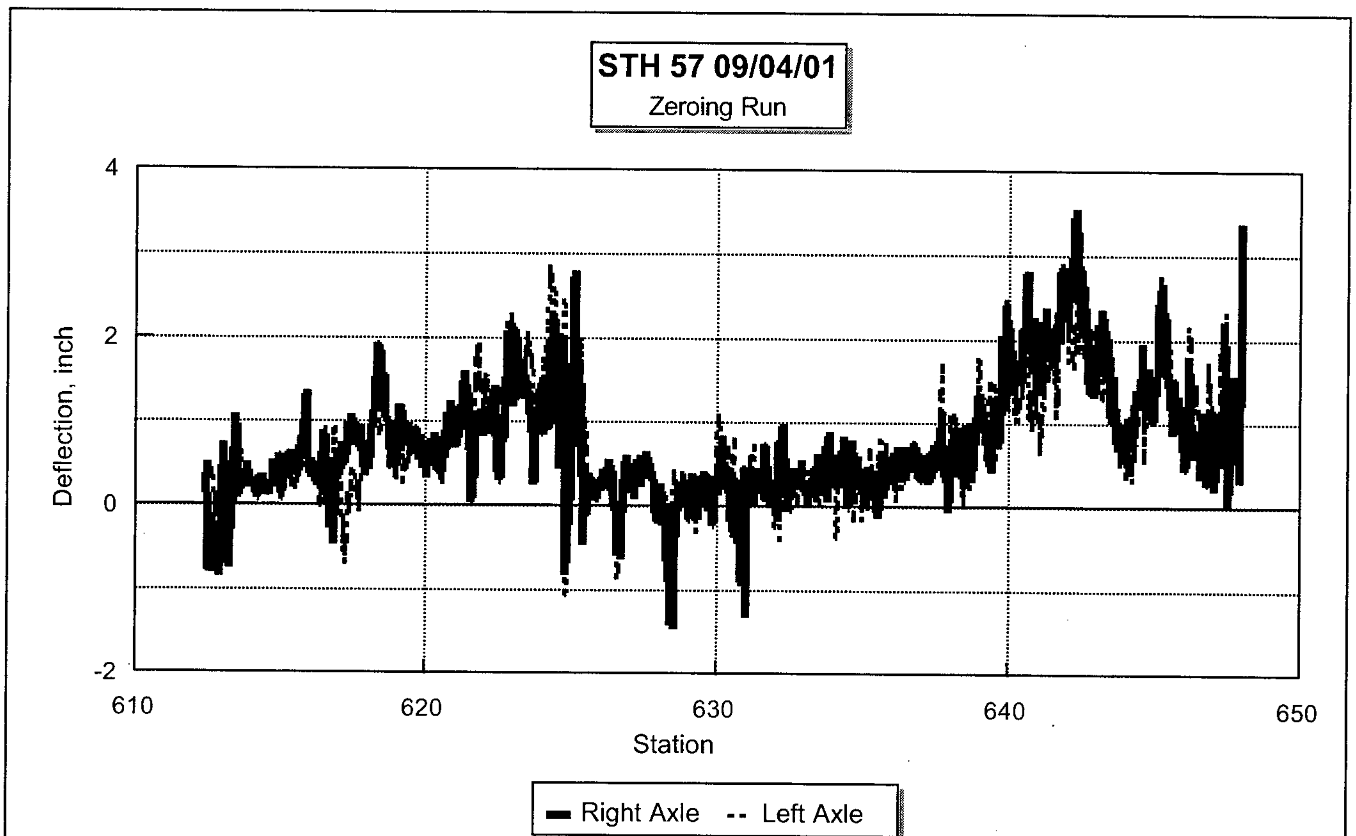

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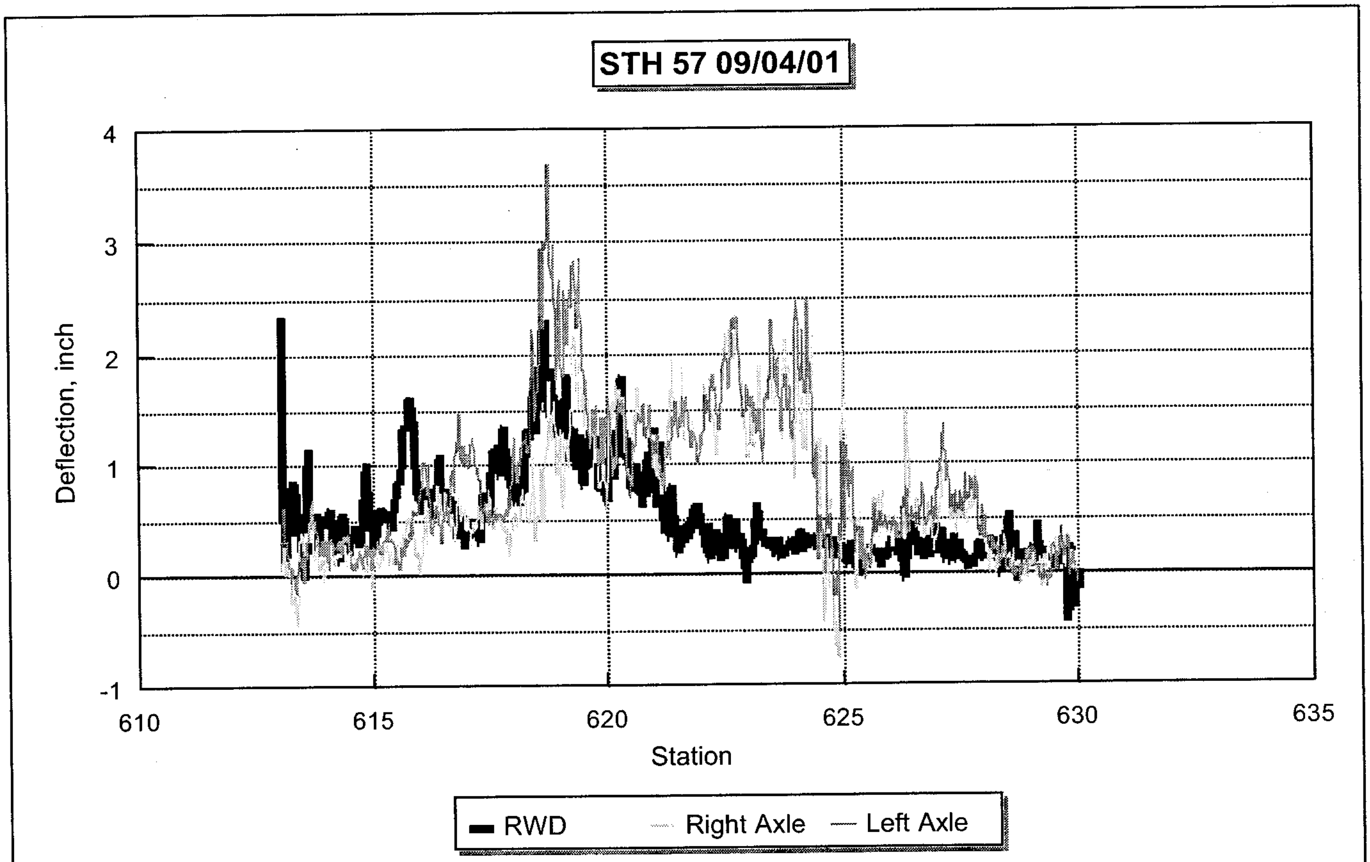

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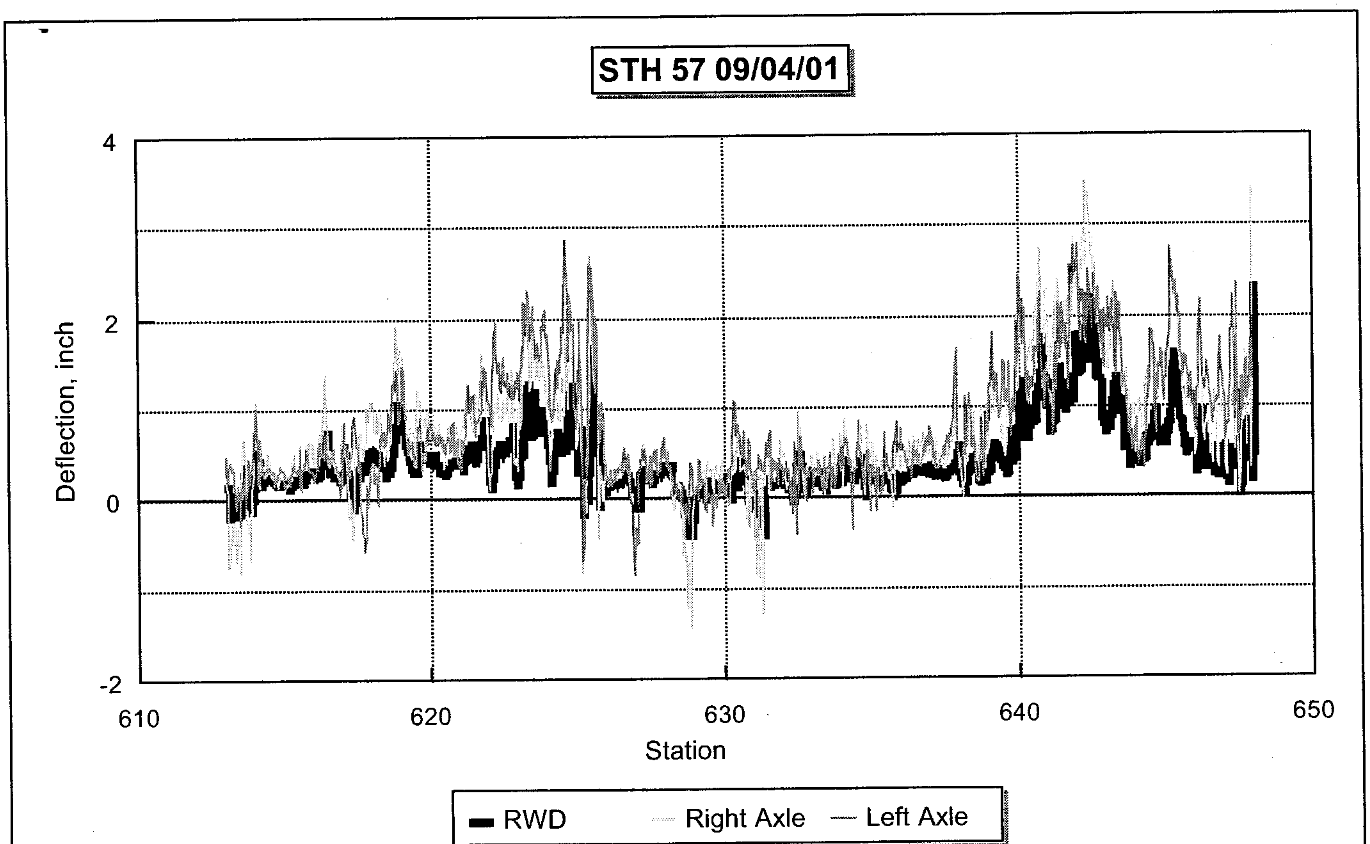

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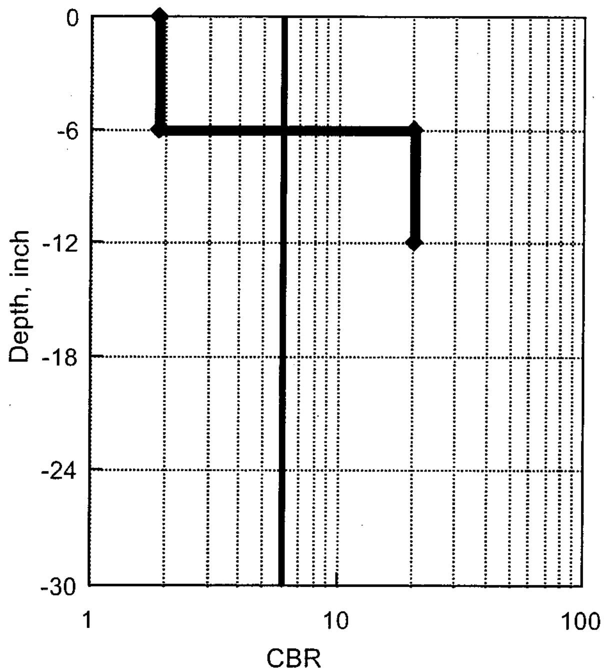

Figure 2.4.7

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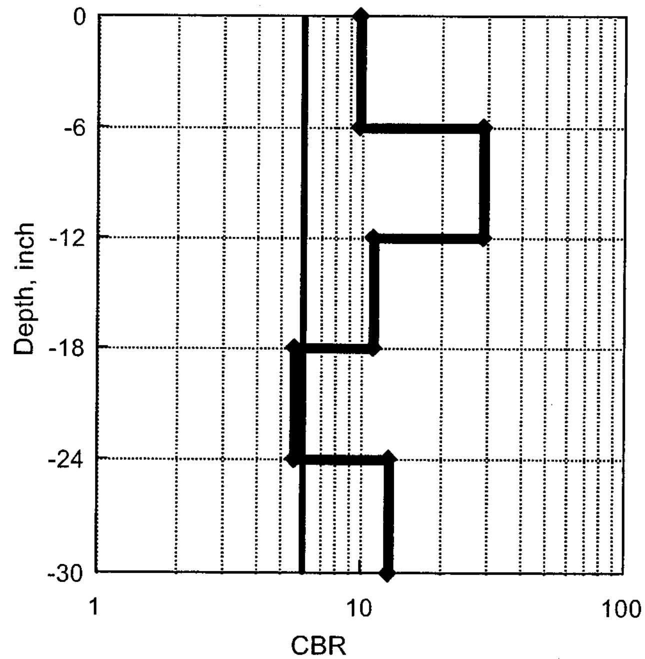

Figure 2.4.8

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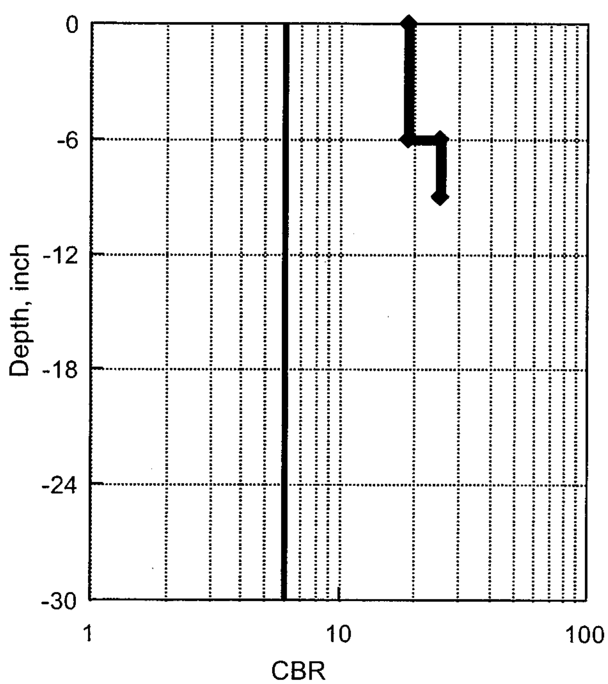

Figure 2.4.9

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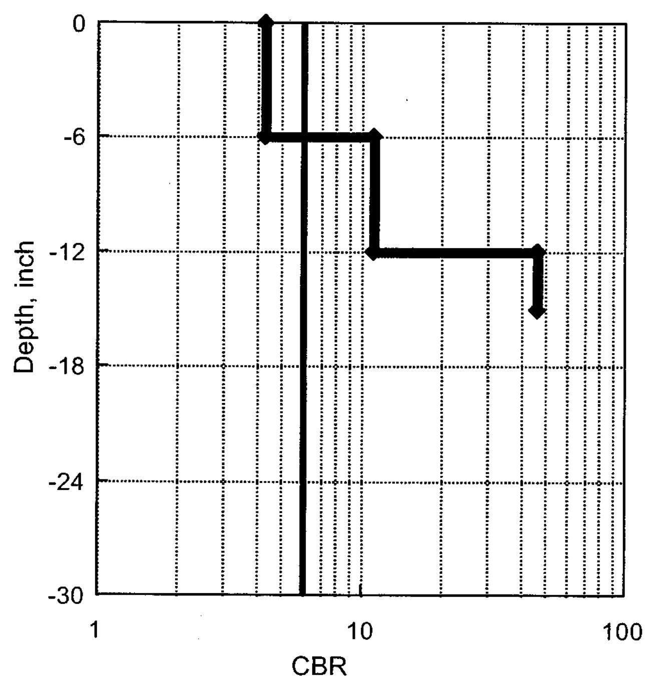

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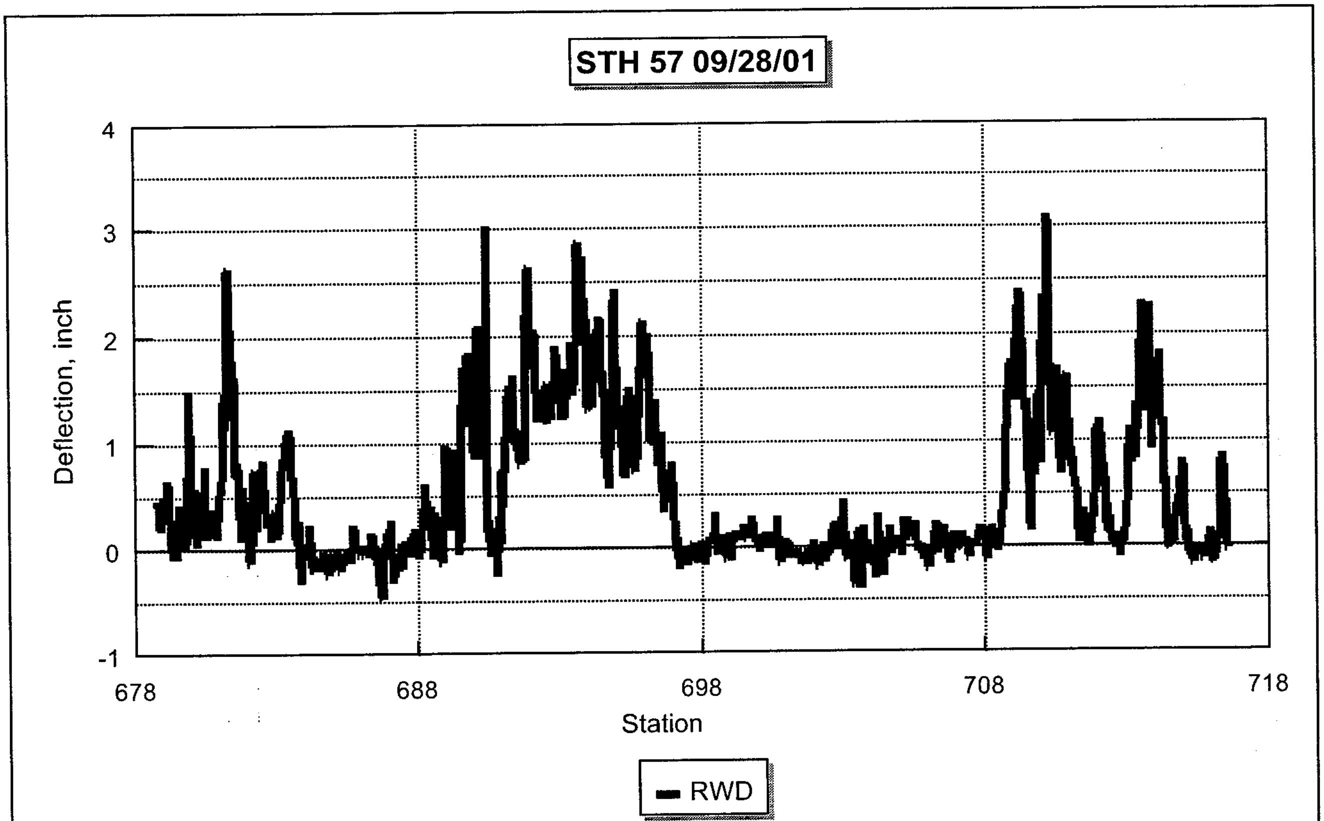

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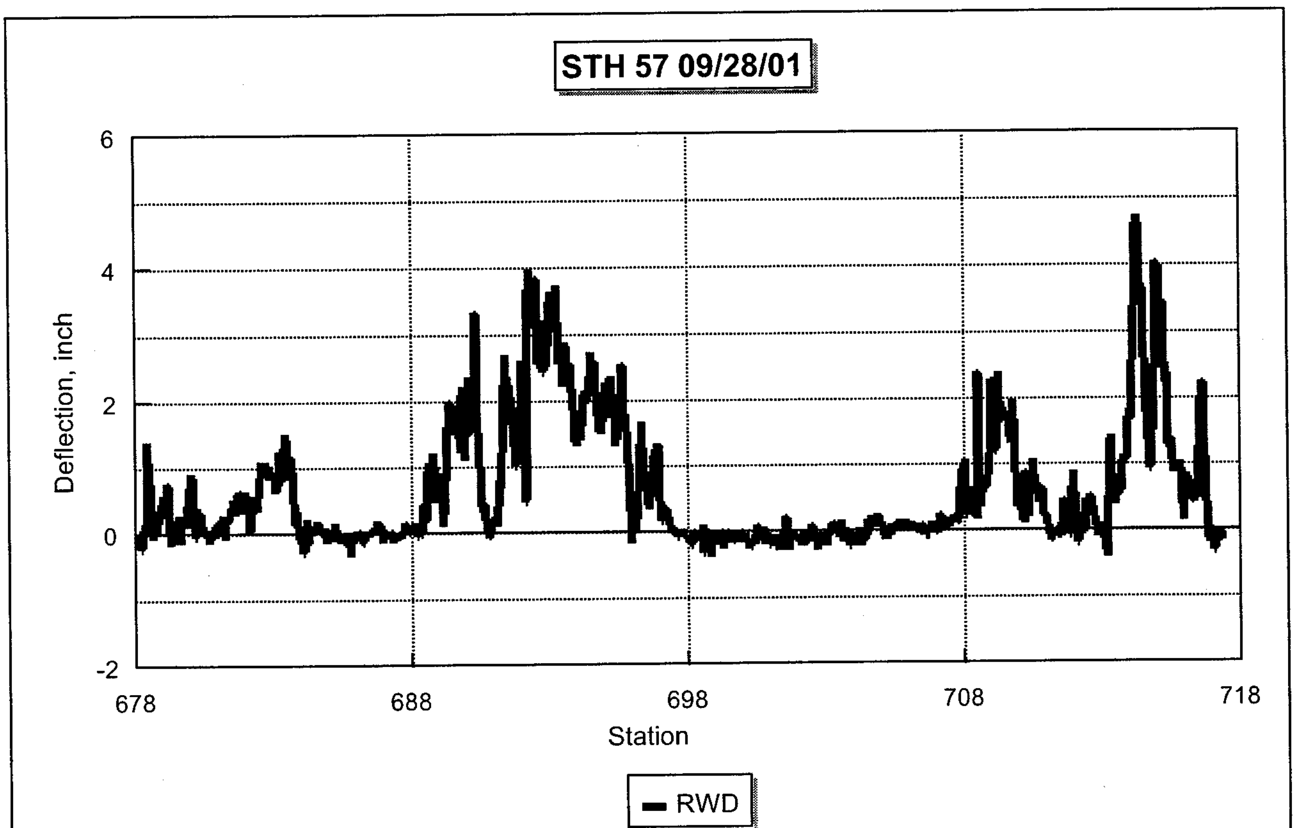

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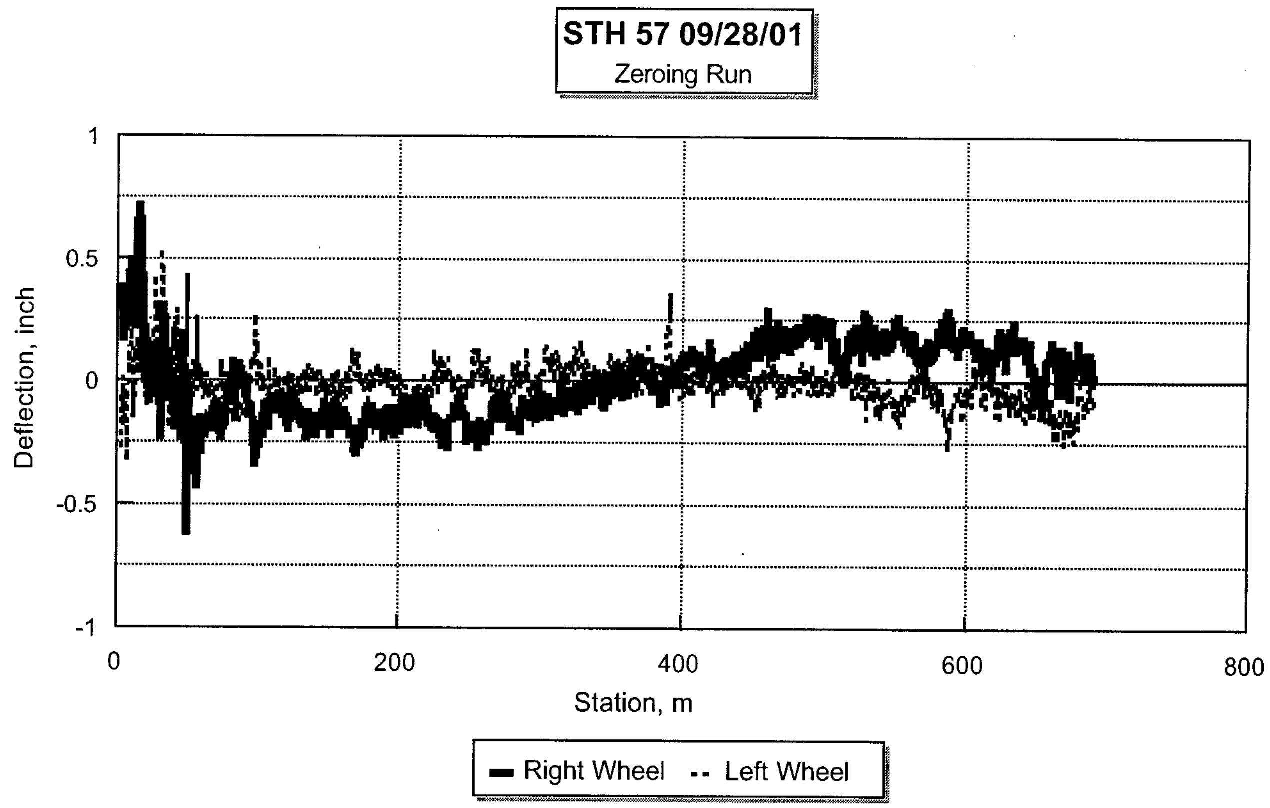

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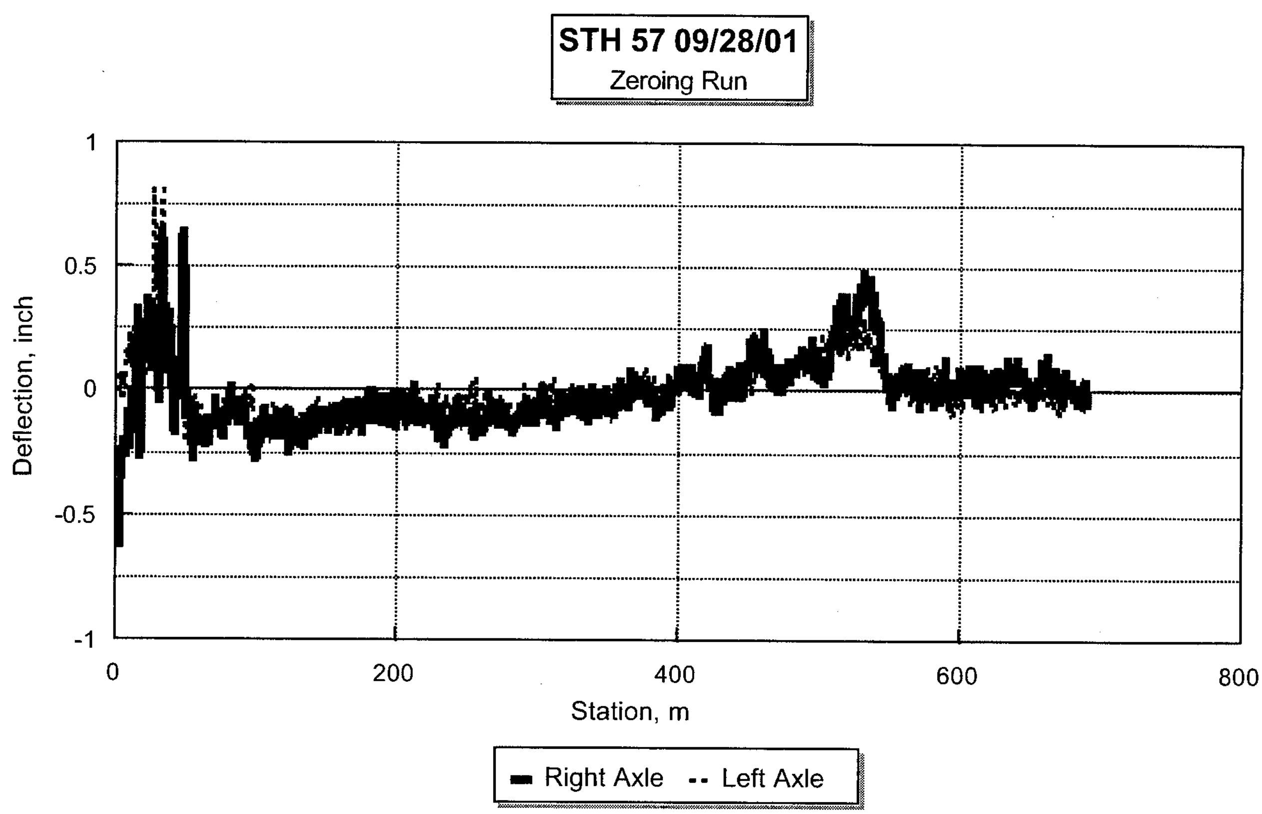

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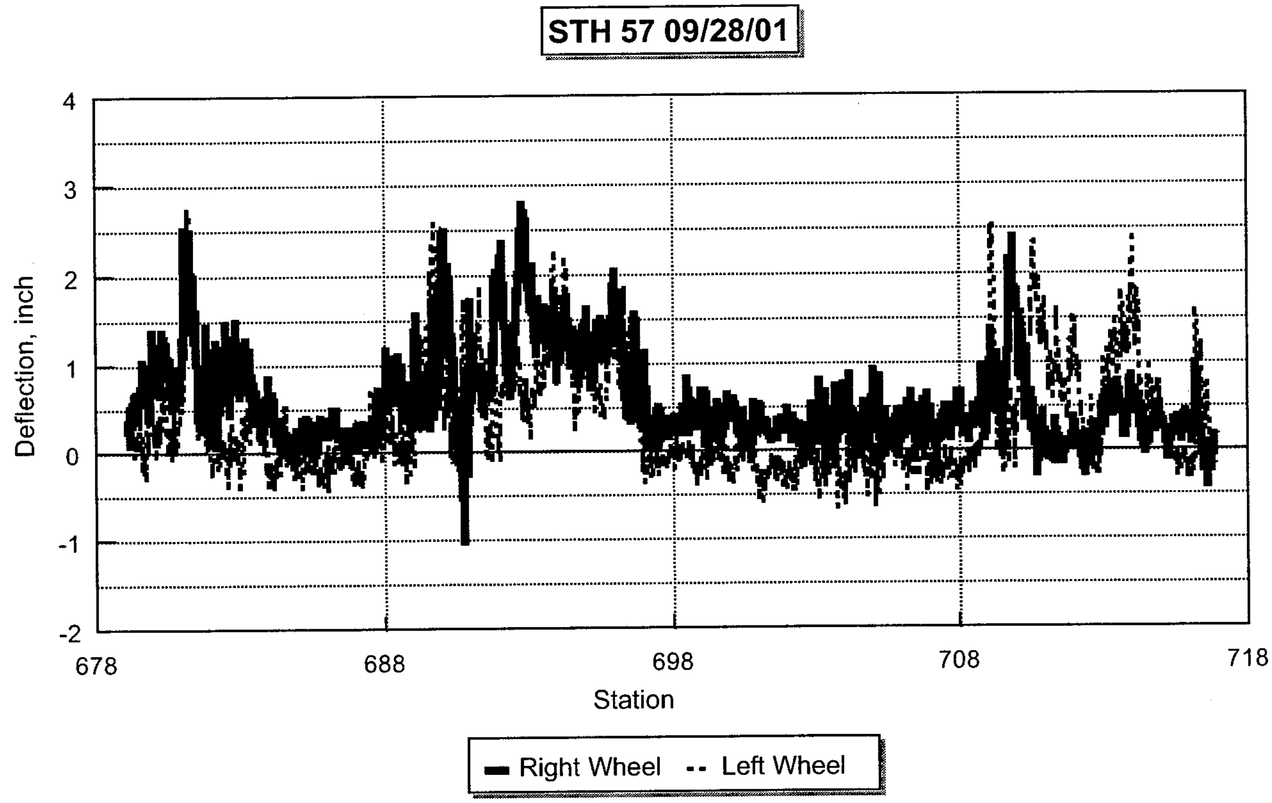

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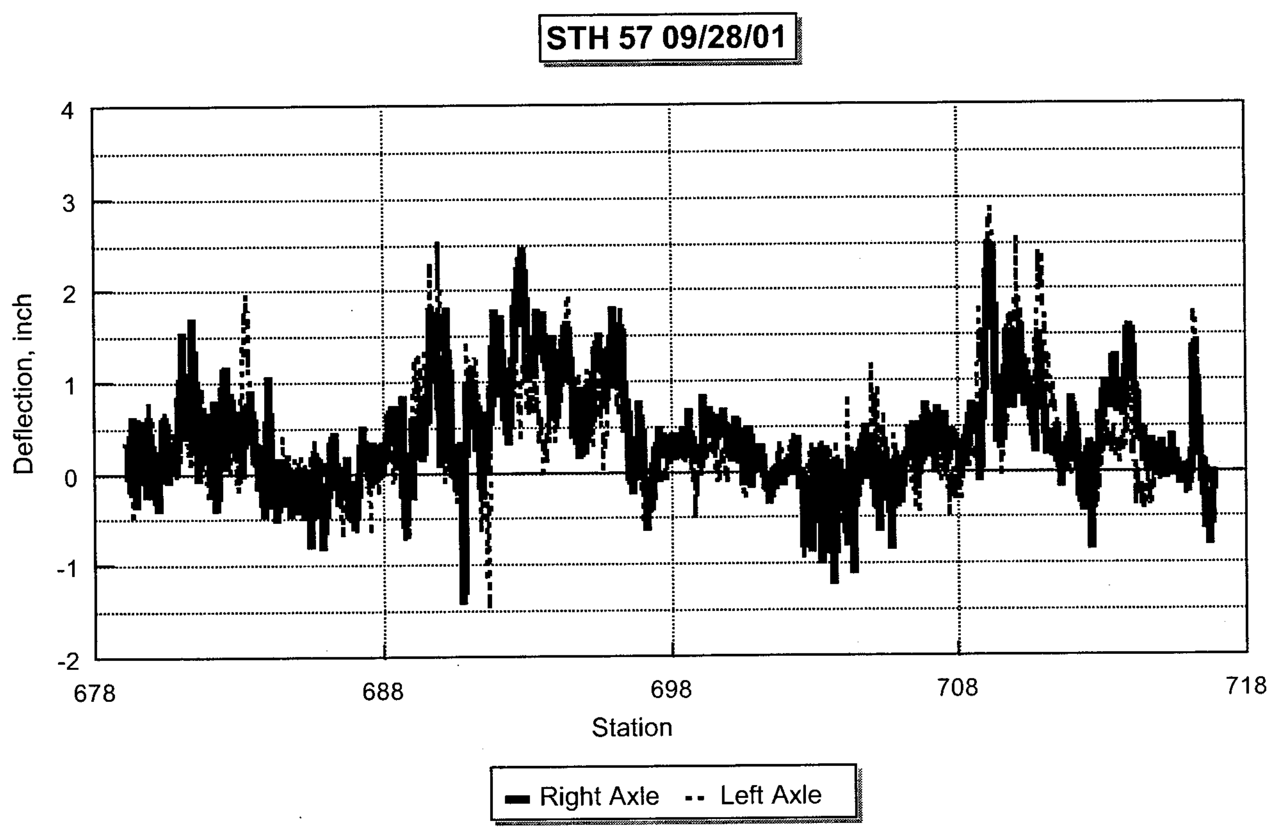

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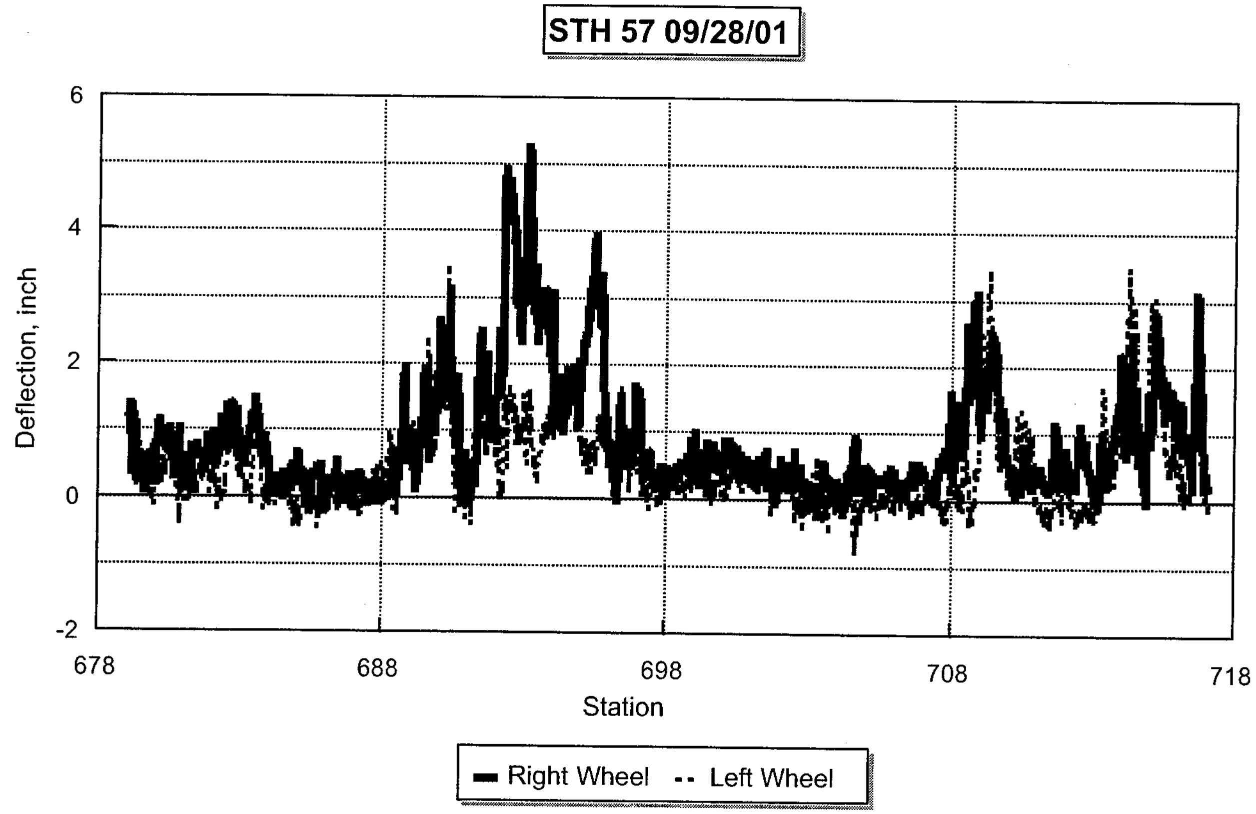

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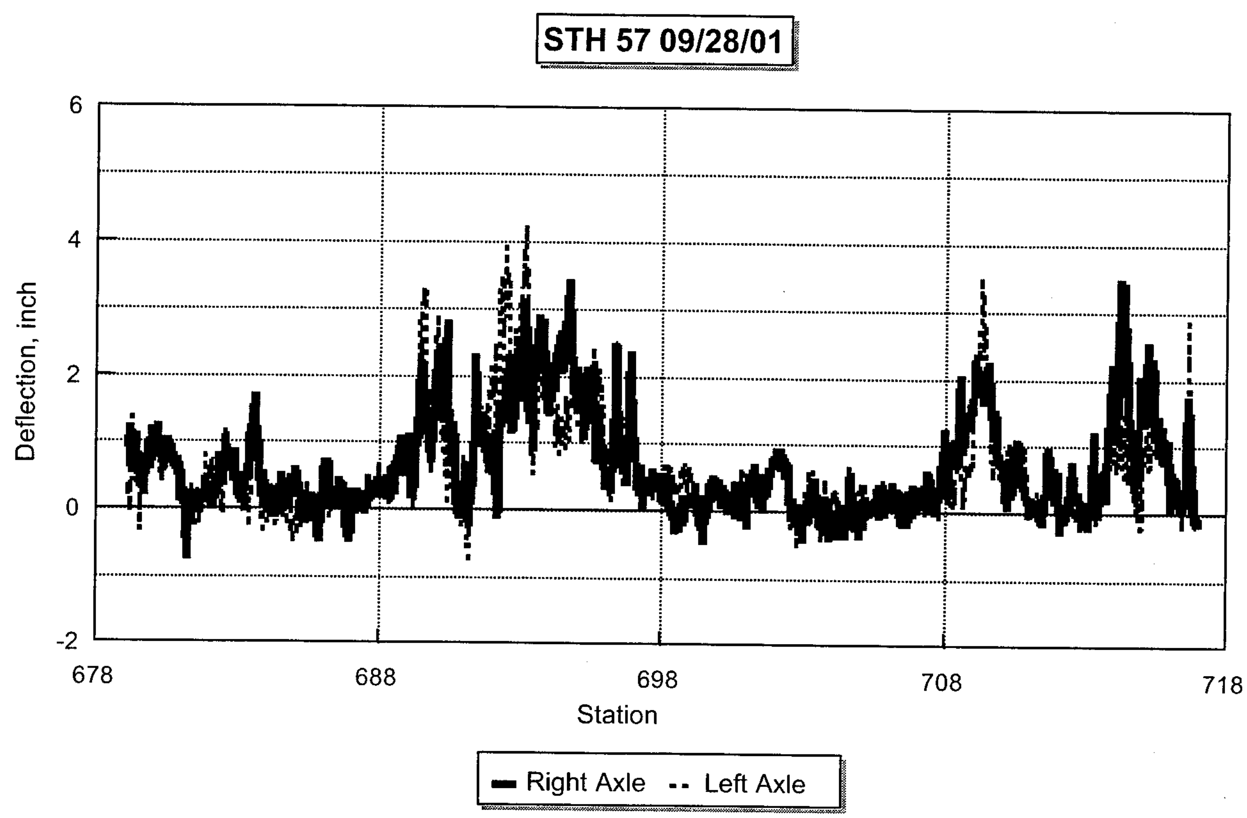

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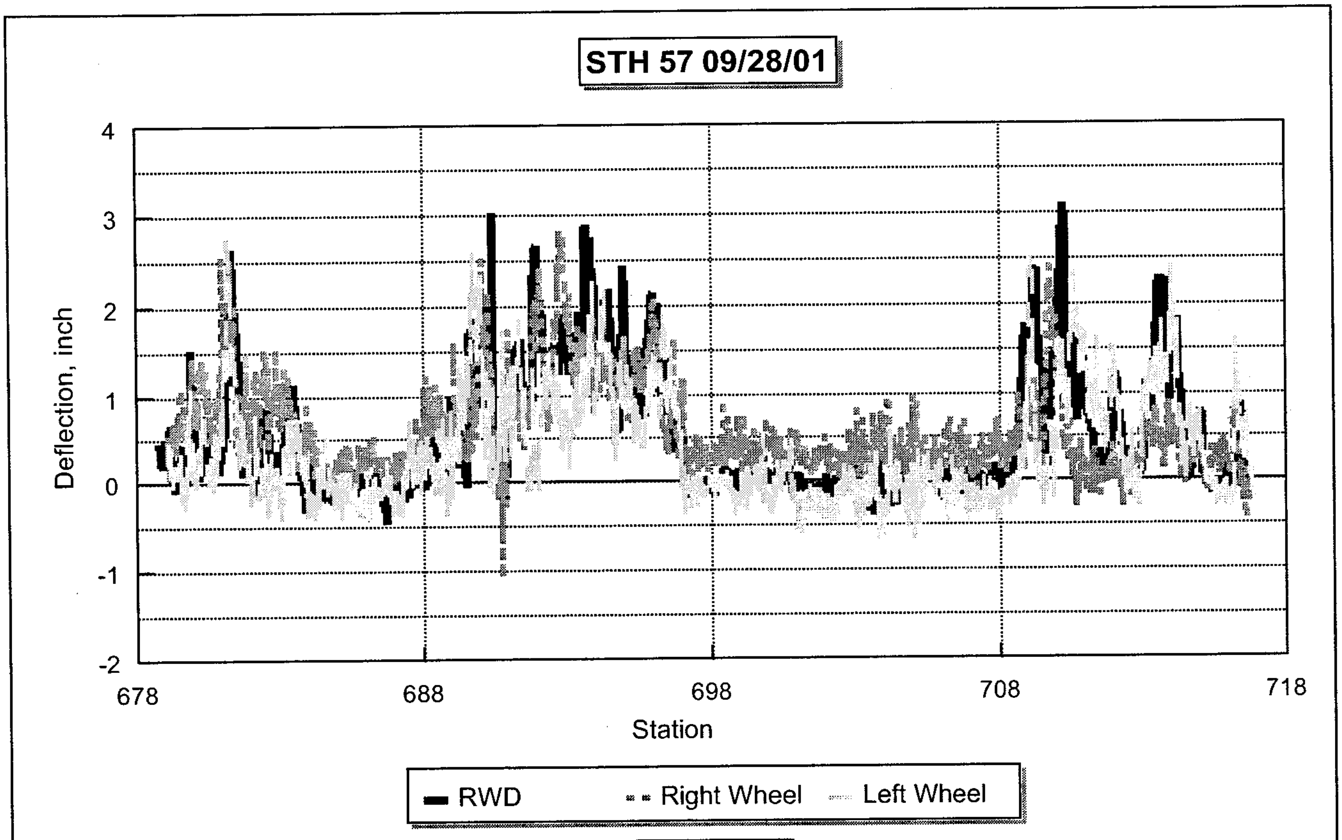

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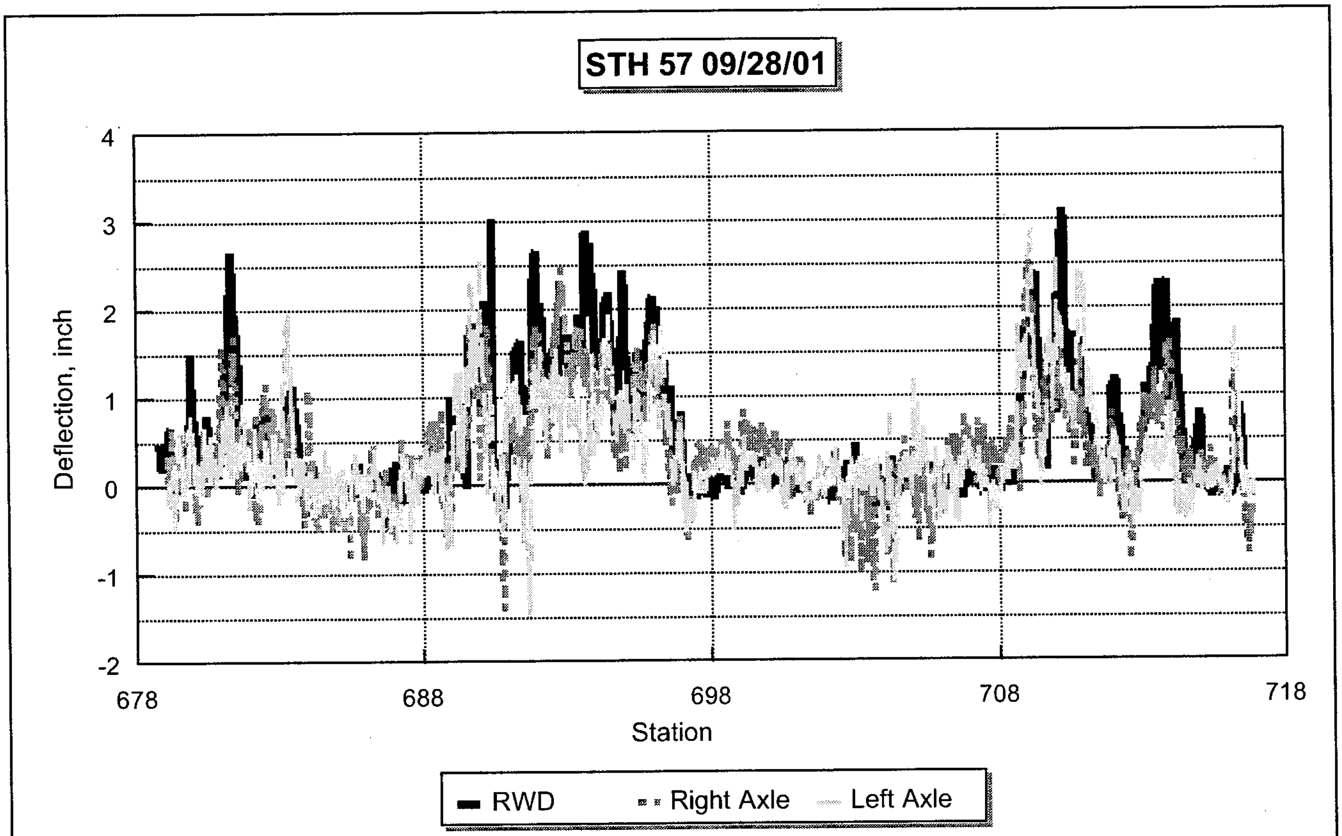

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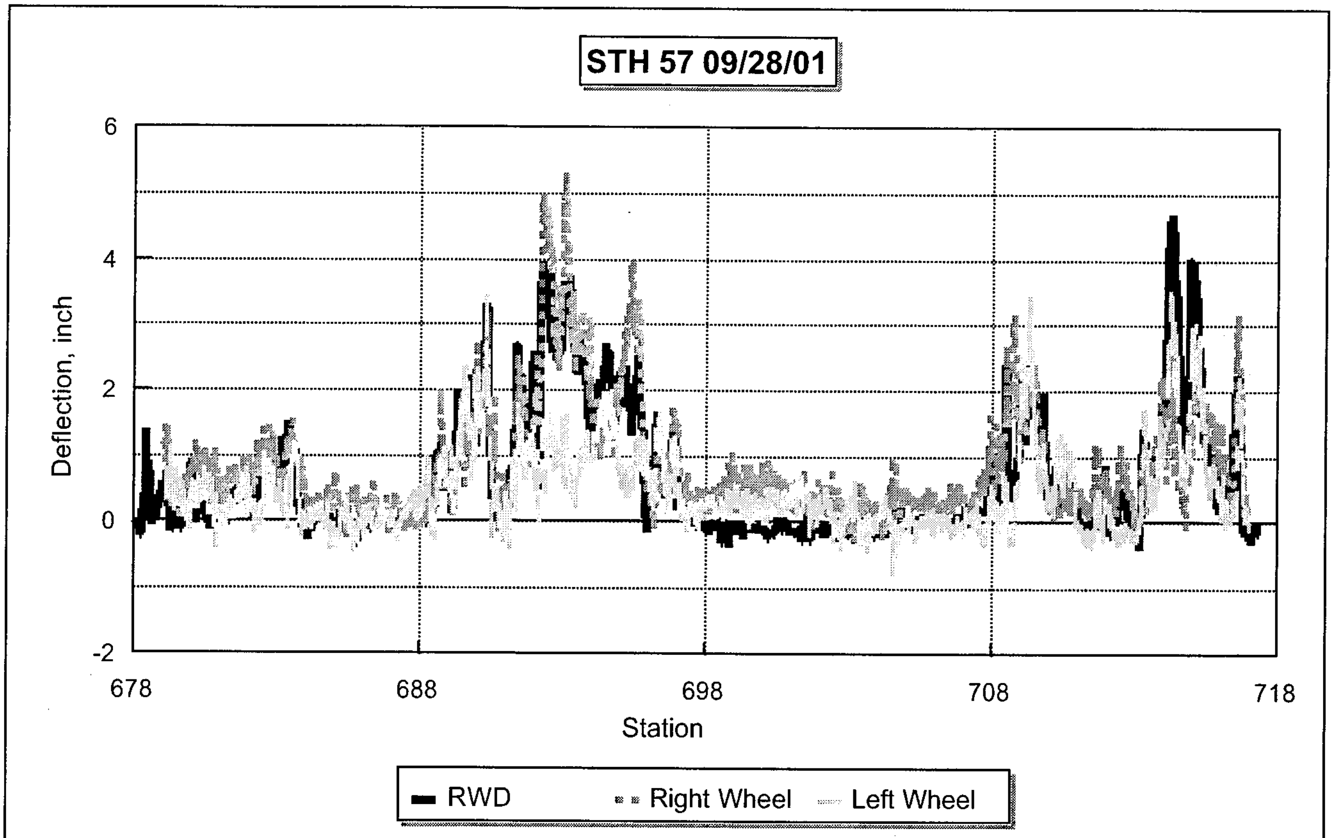

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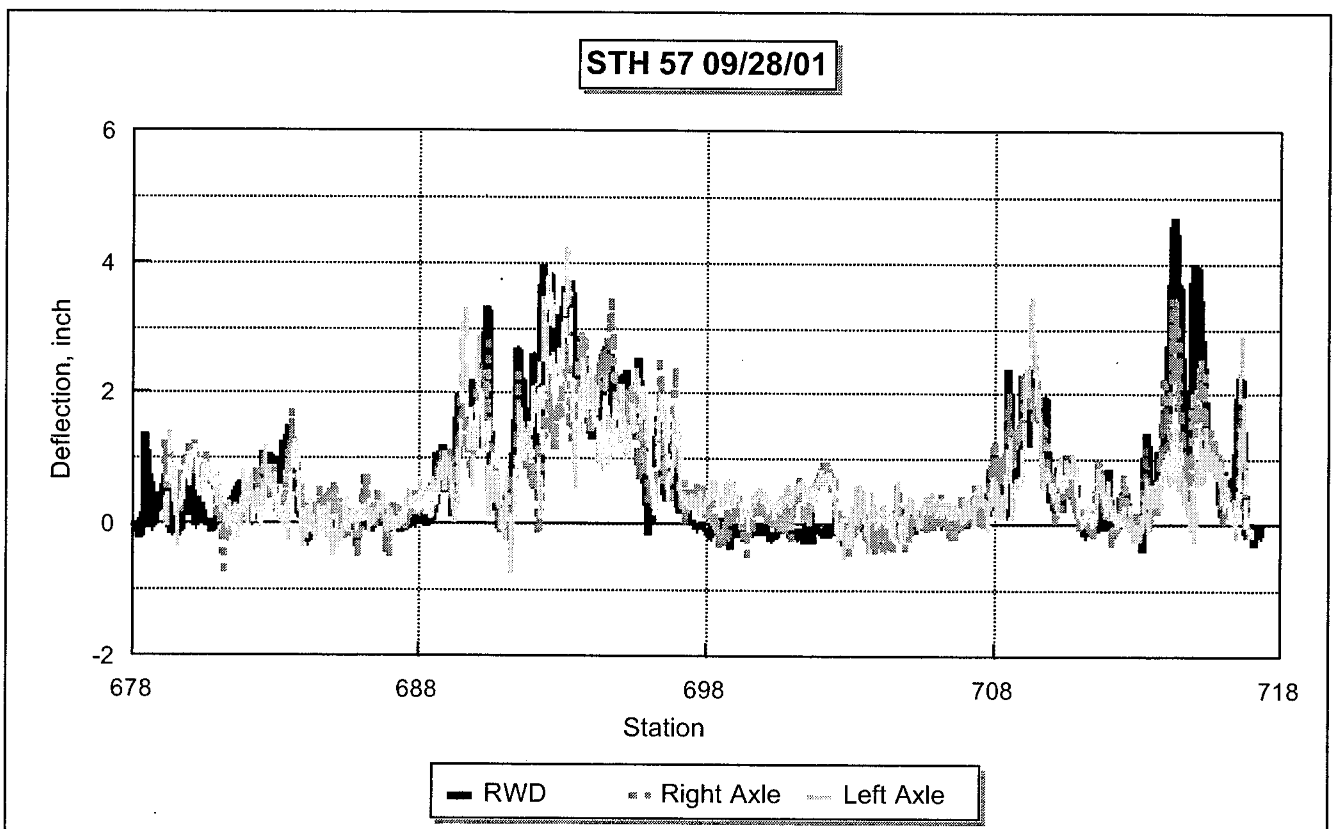

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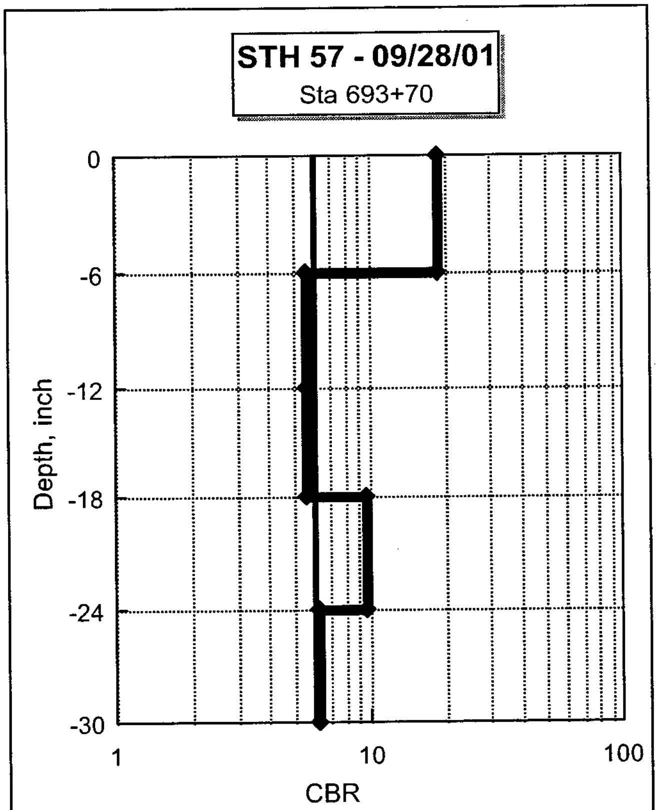

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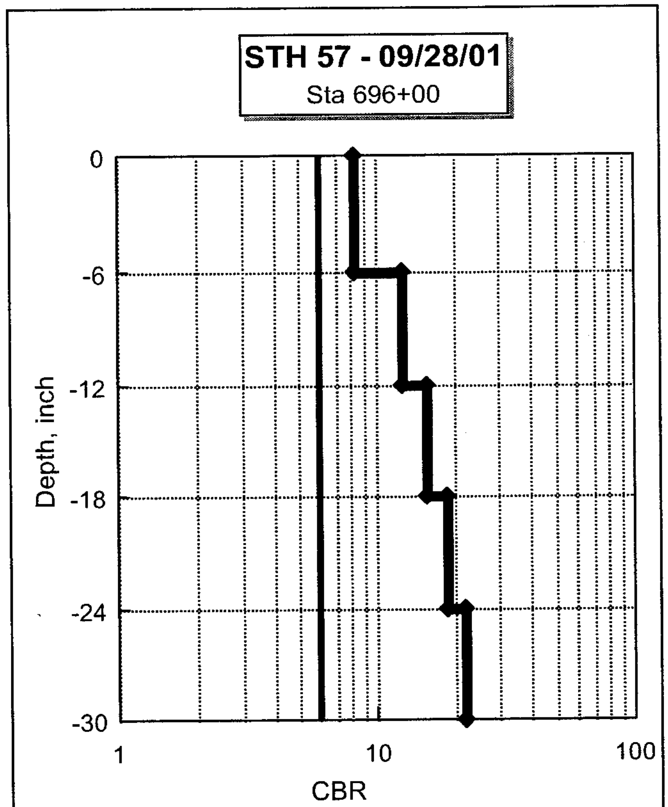

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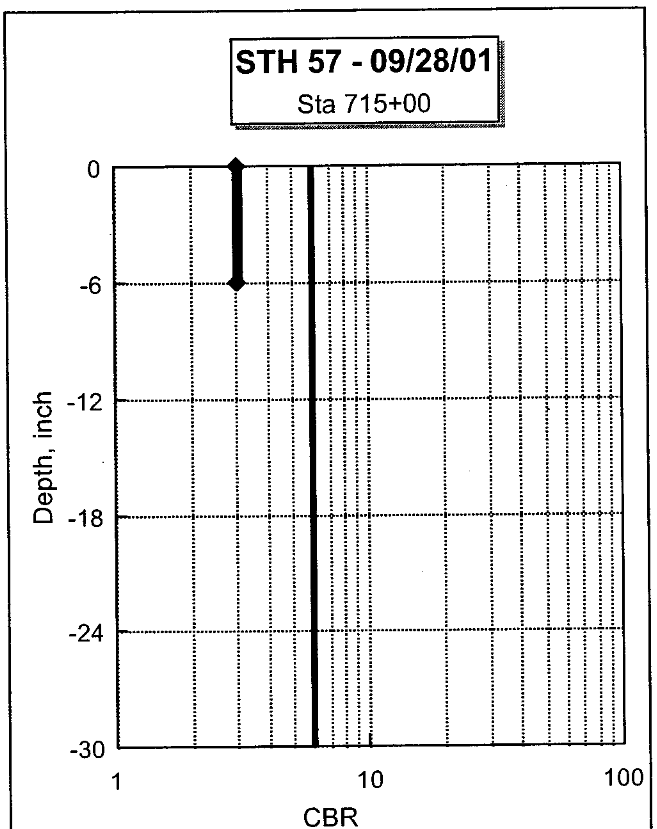

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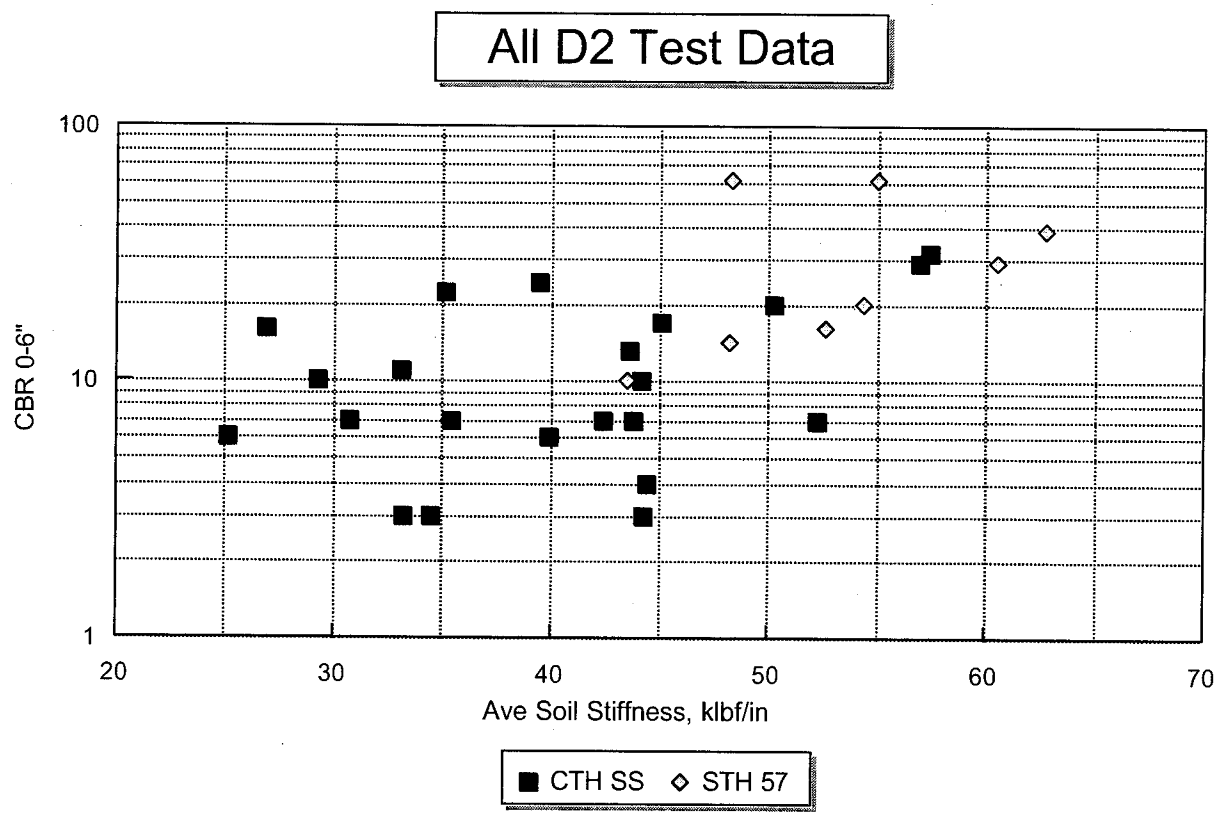

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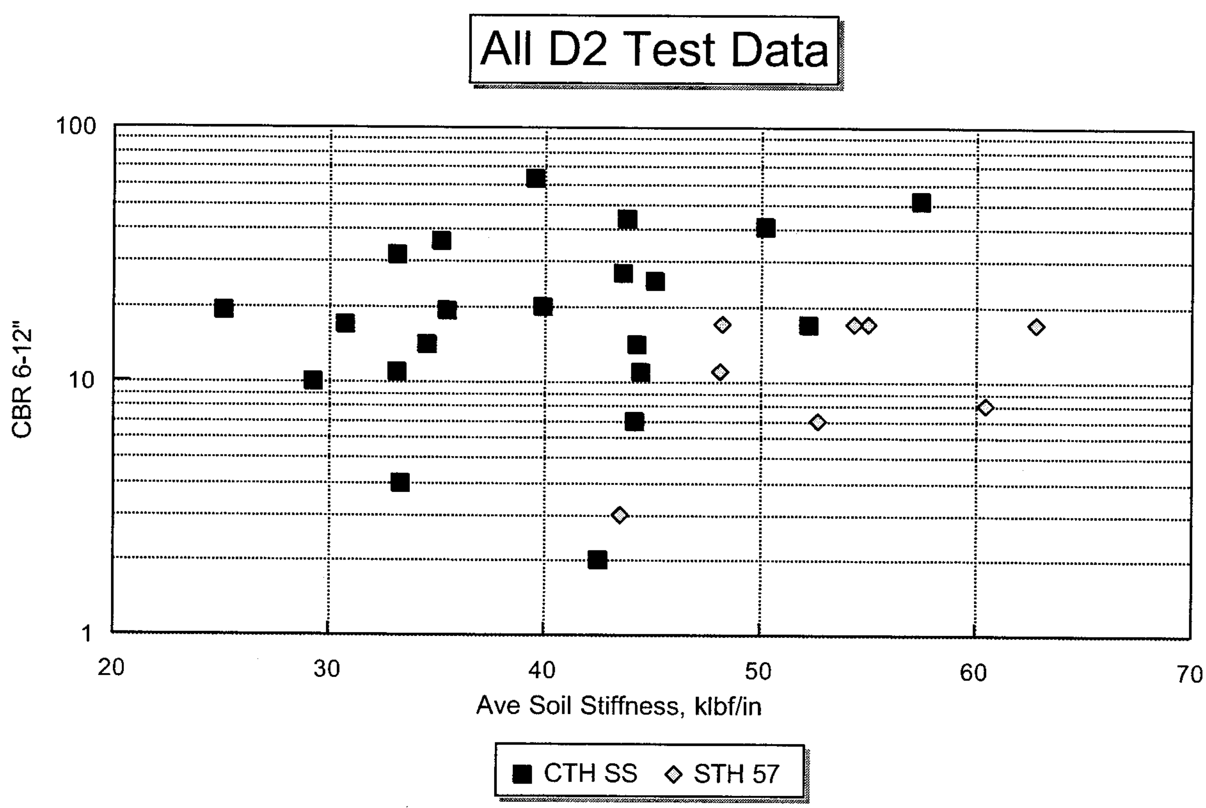

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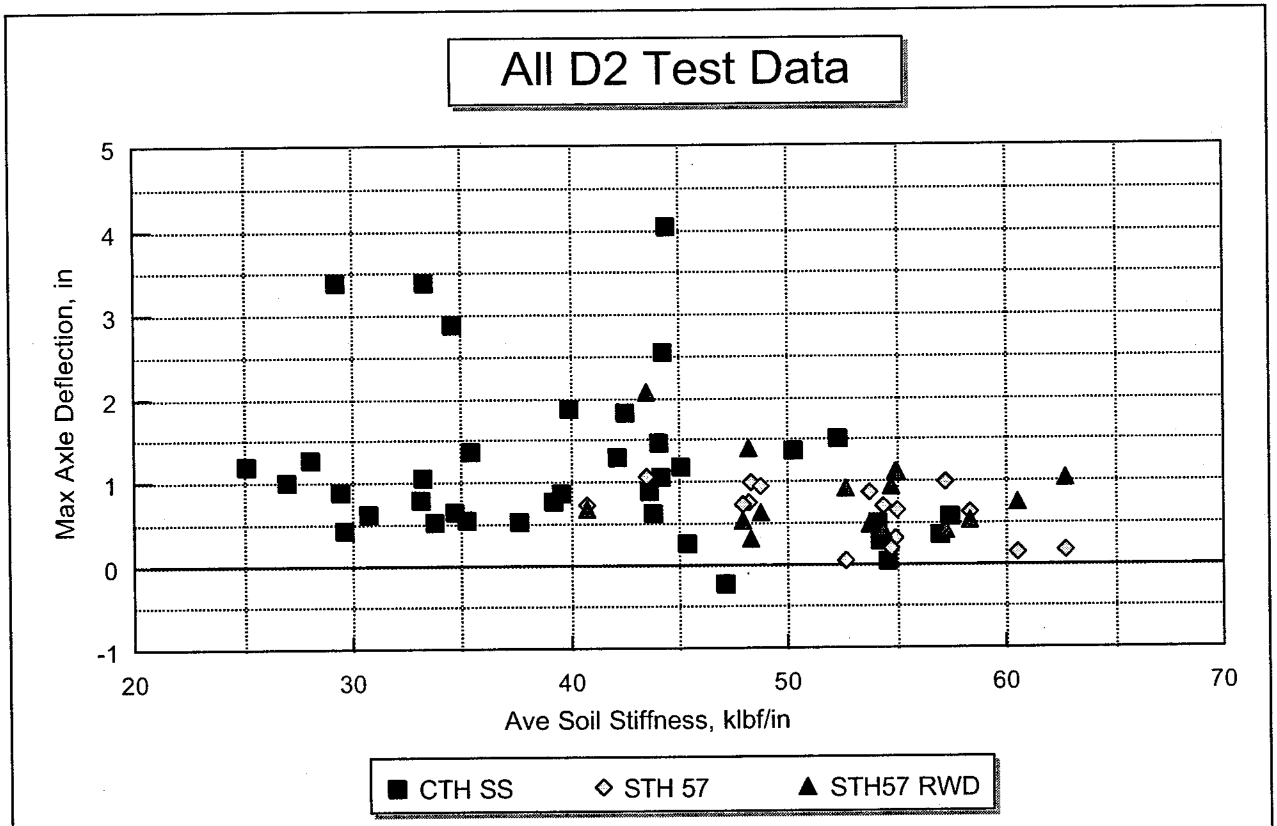

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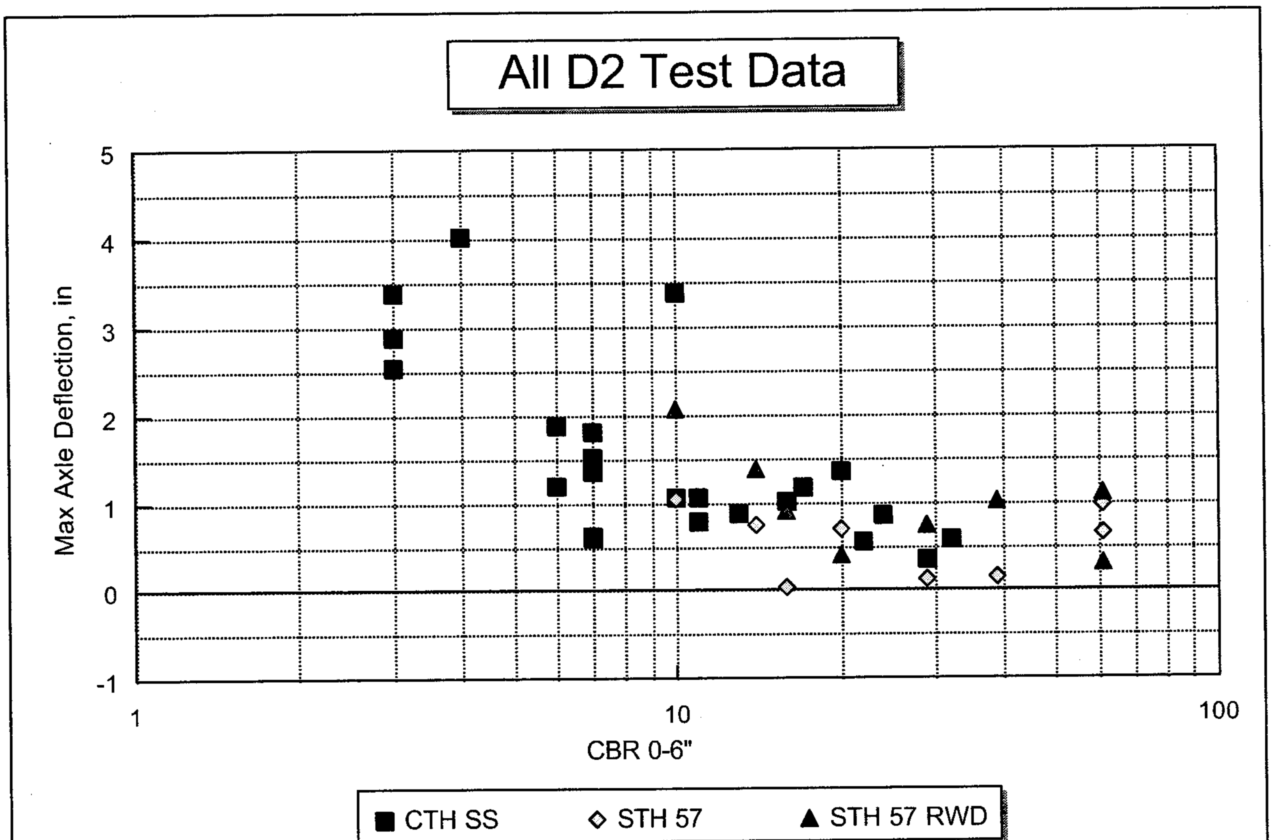

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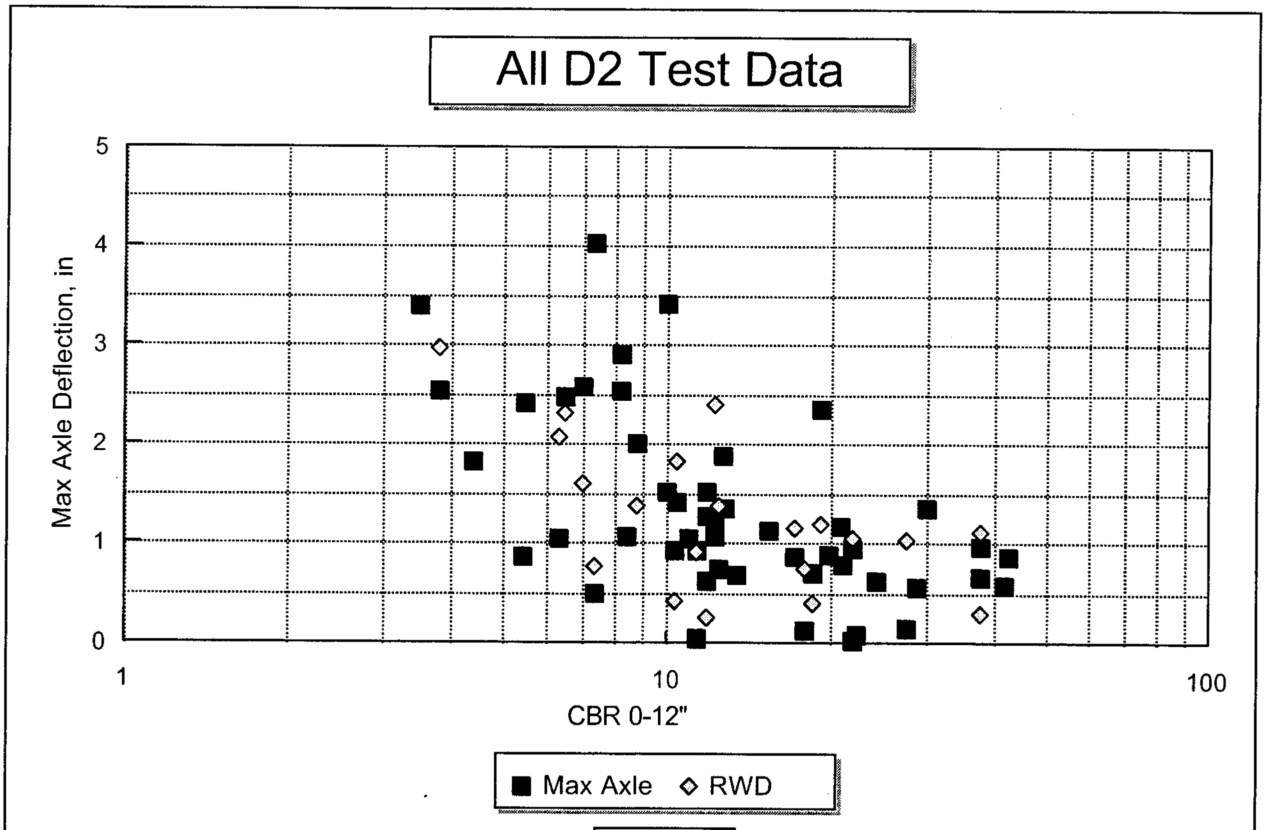

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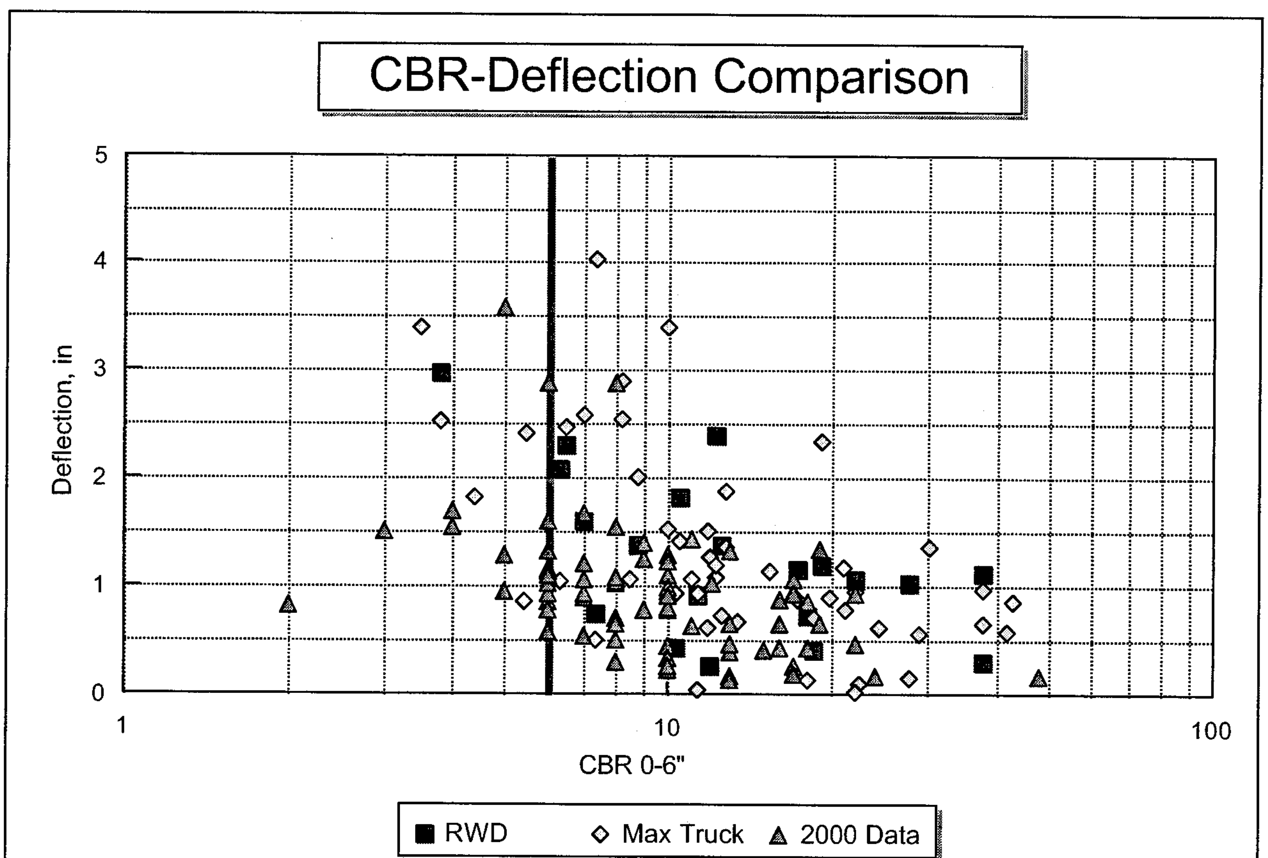

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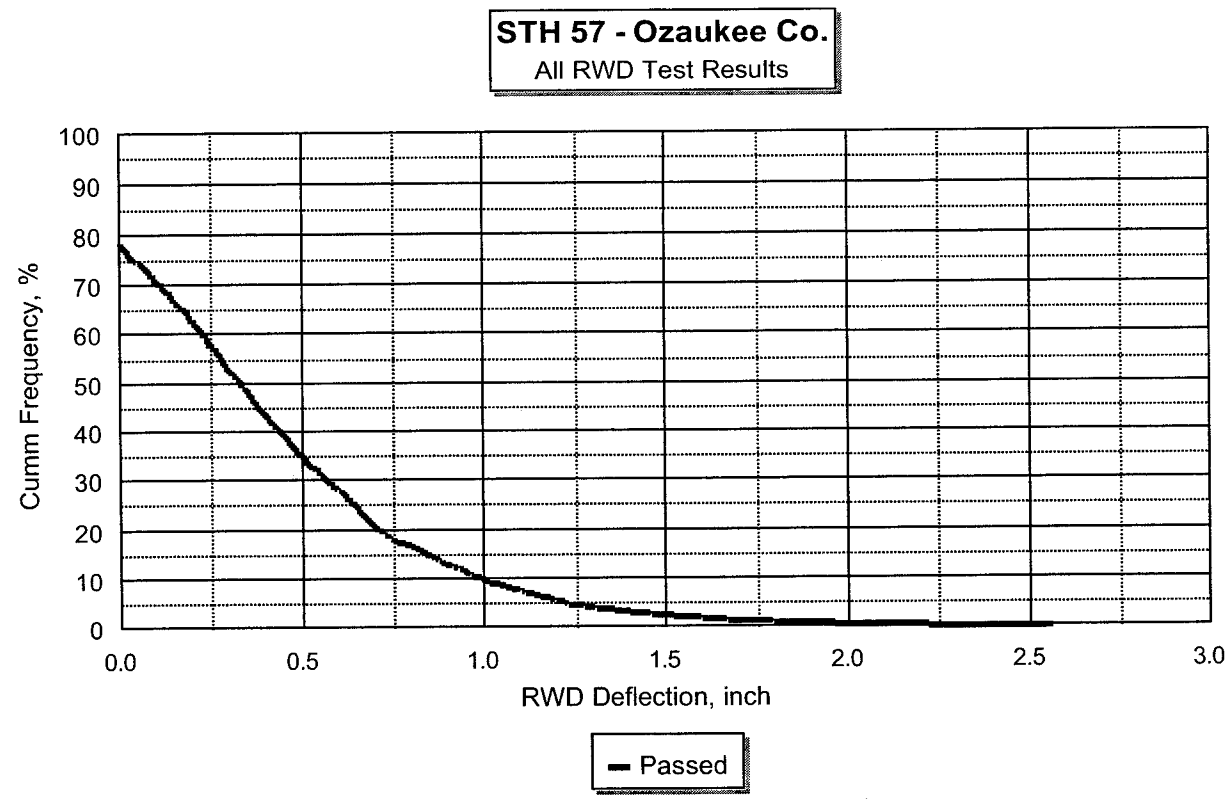

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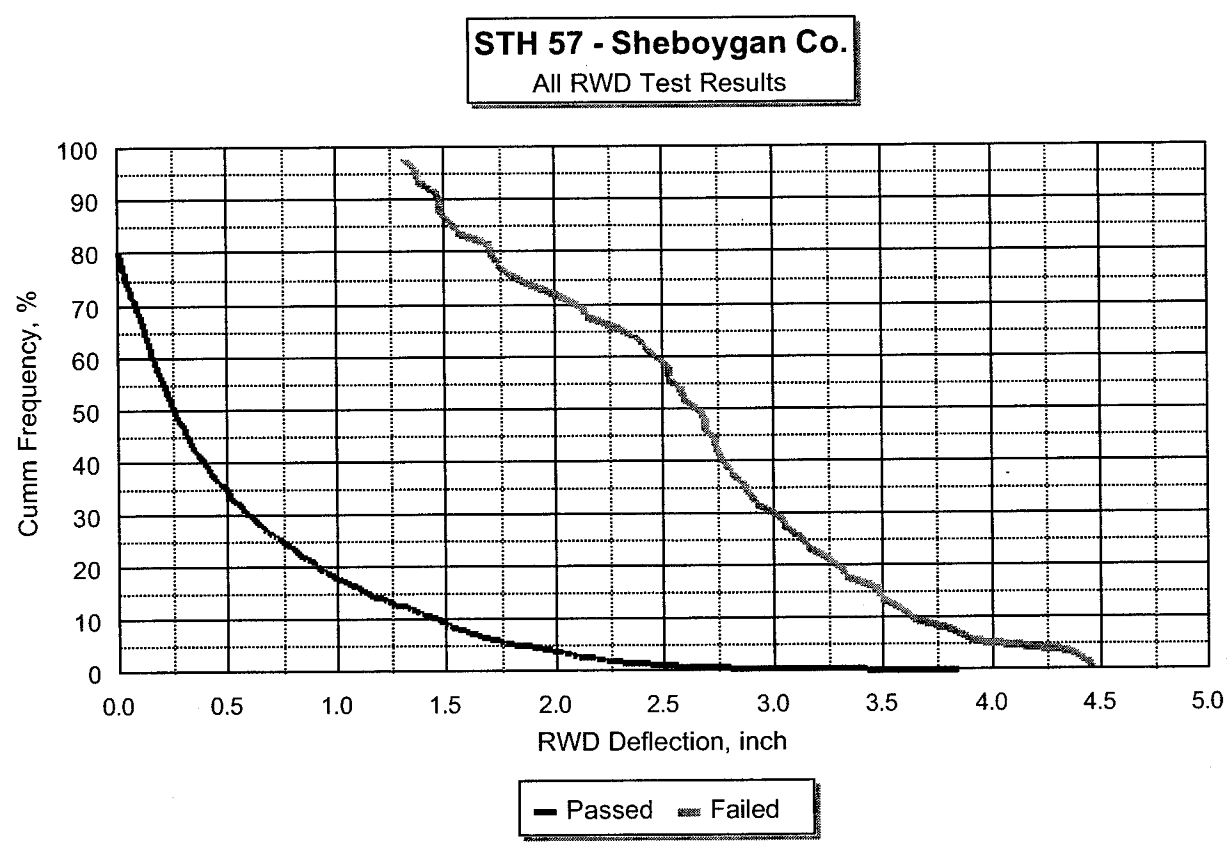

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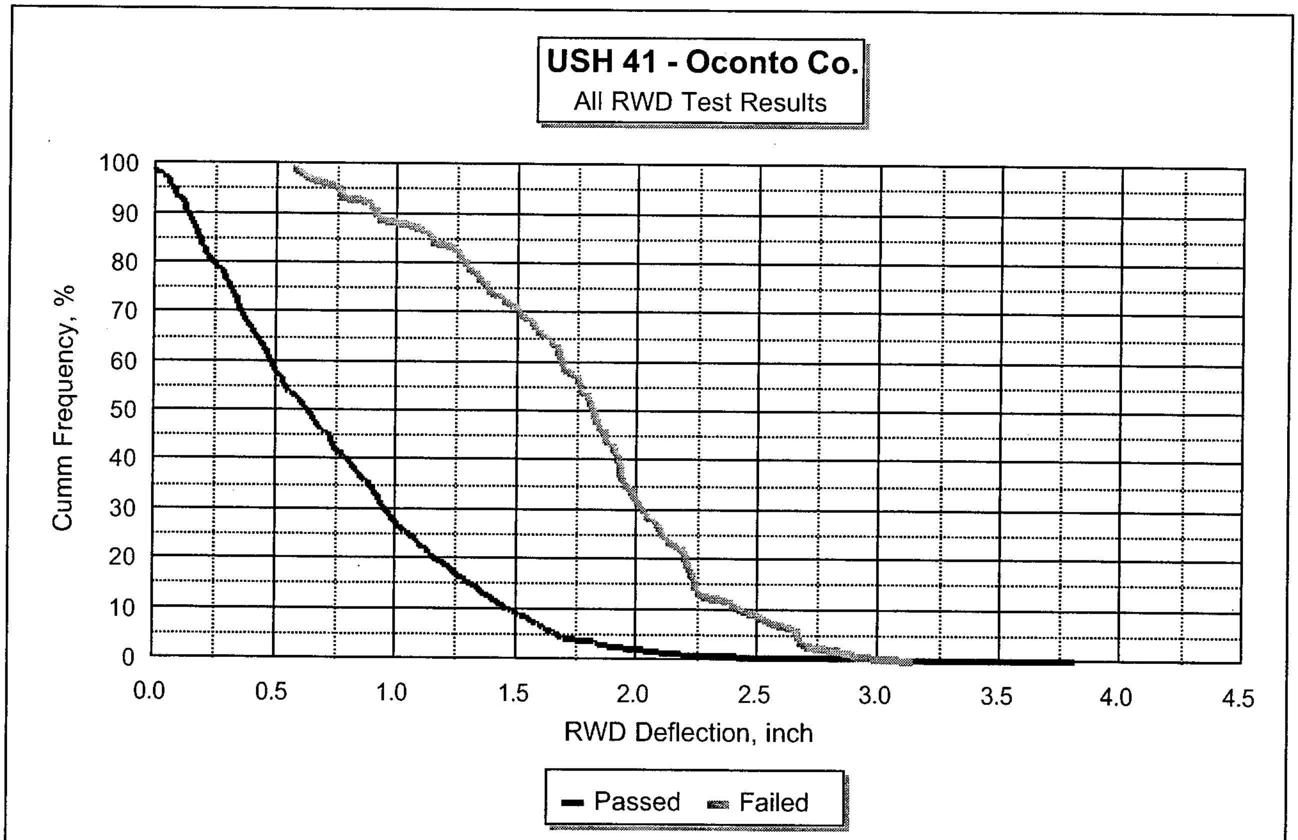

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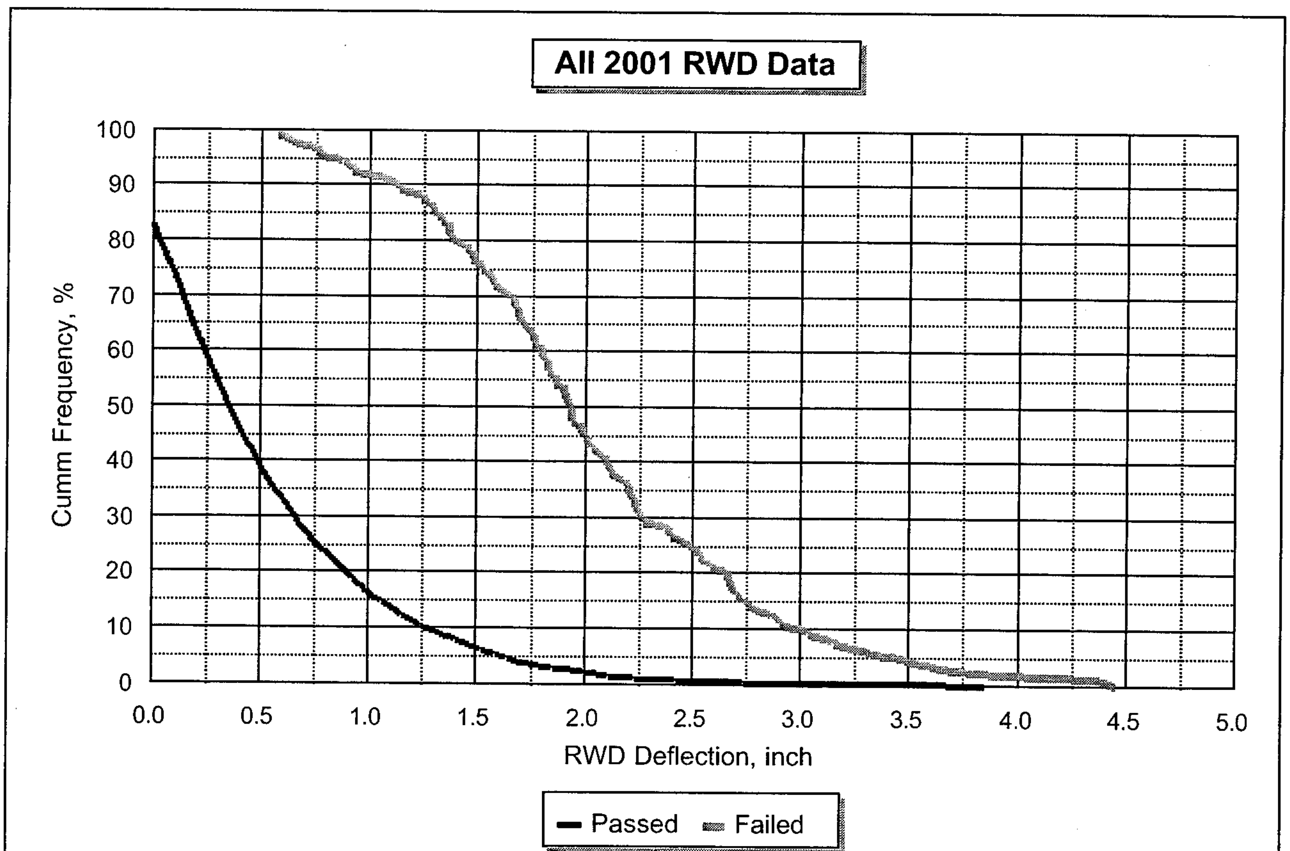

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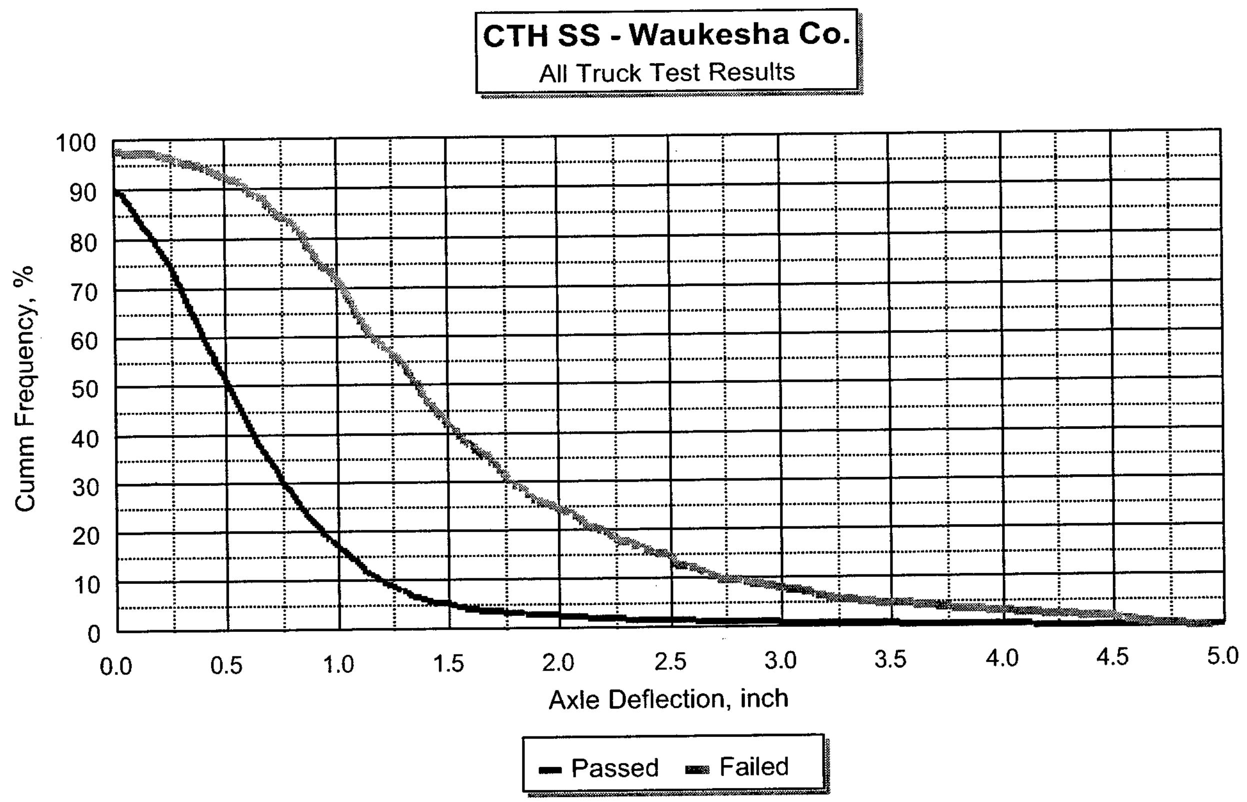

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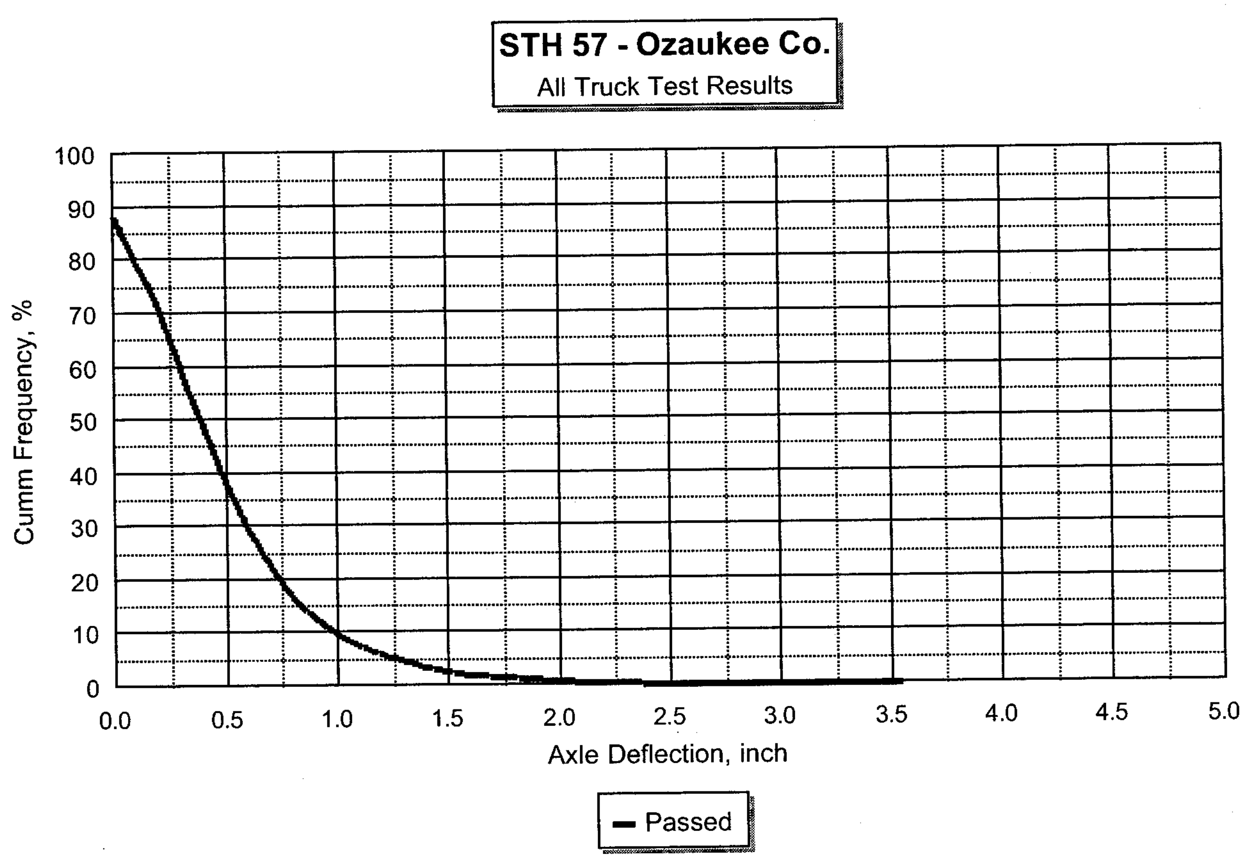

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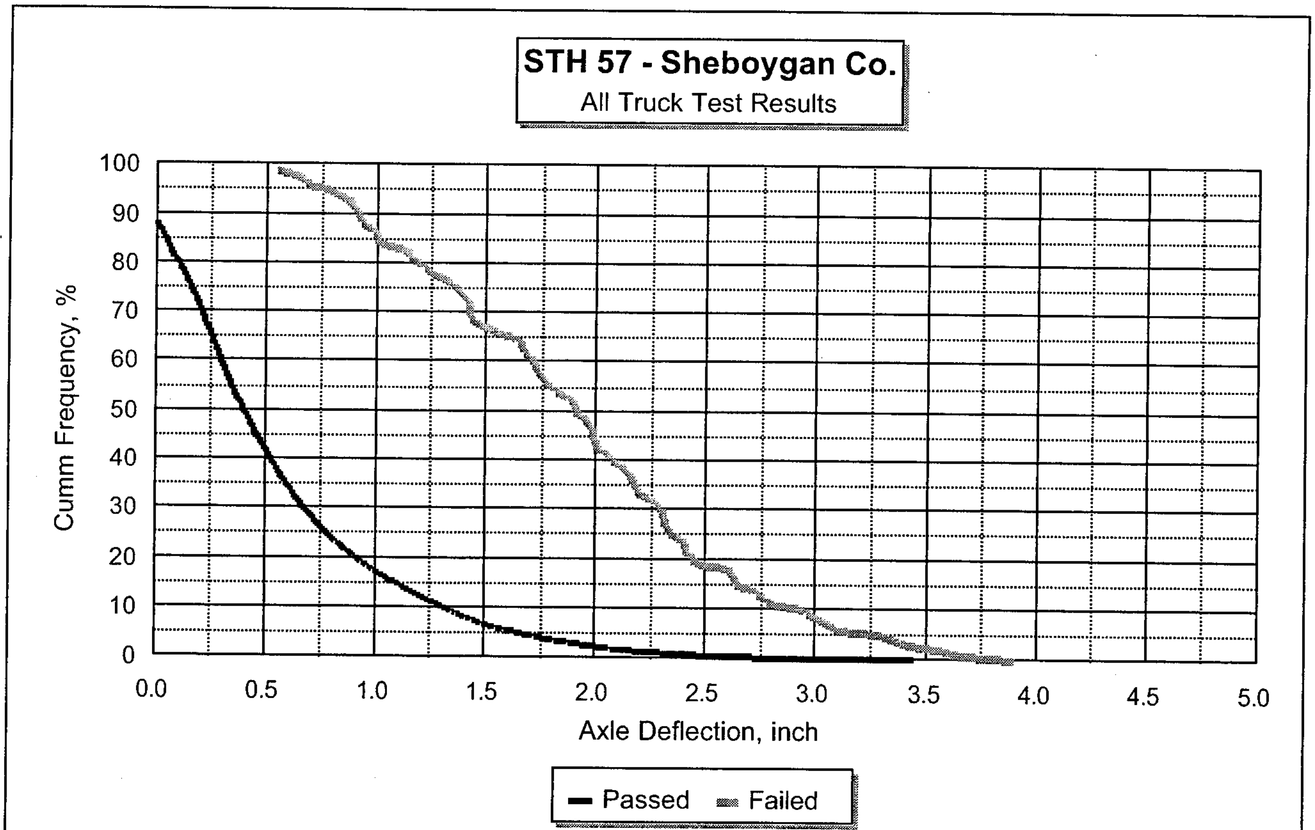

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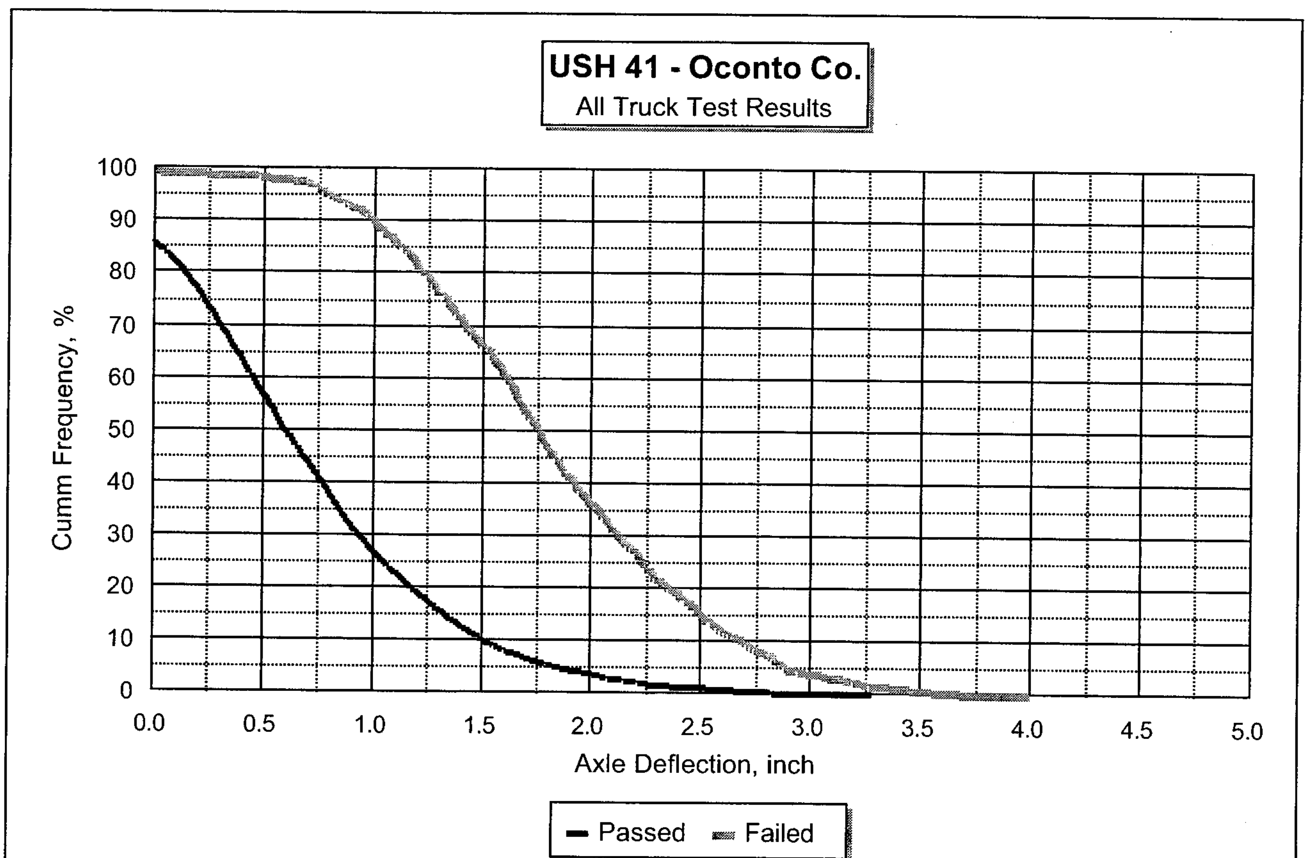

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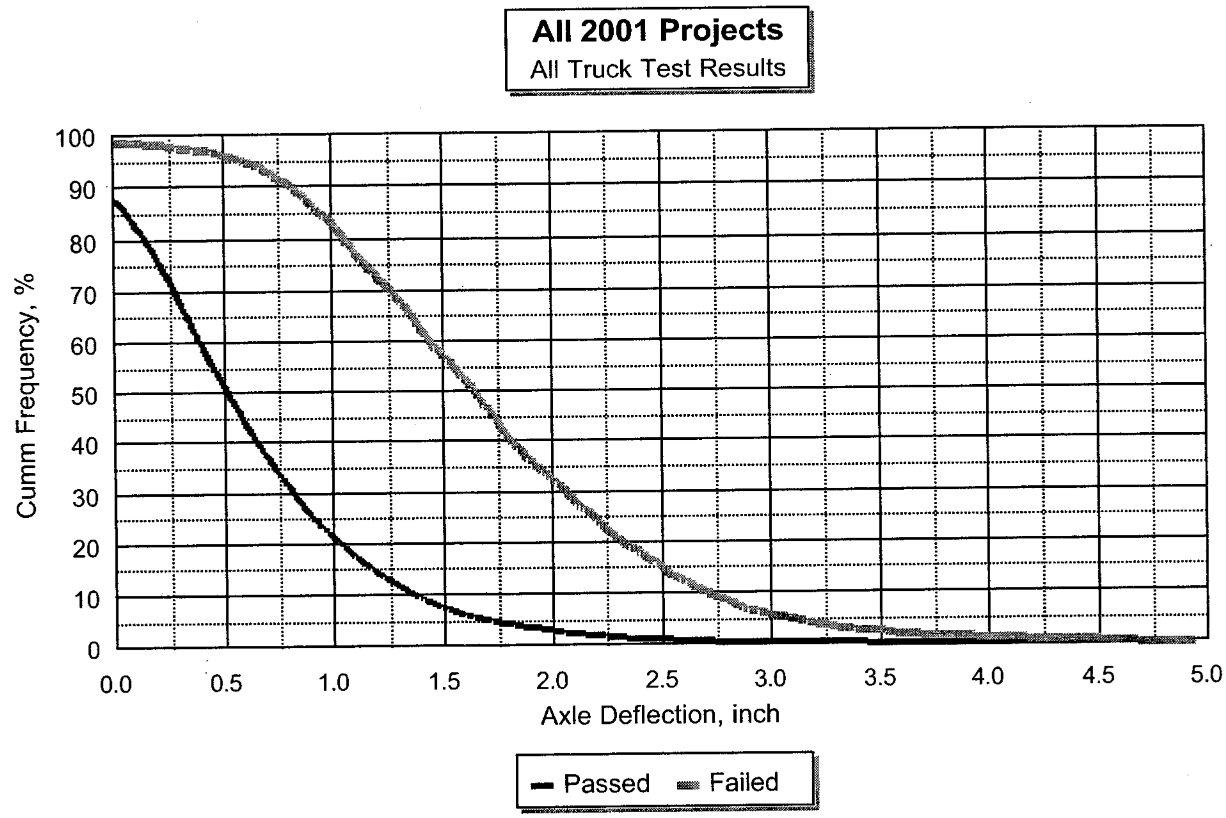
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80
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50
40
30
20
10
0
Cumm Frequency, %
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0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Axle Deflection, inch
Passed
Failed

Figure 2.5.15